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# Co-benefits of post-2012 global GHG-mitigation policies

*ClimateCost (The Full Costs of Climate Change)*
*Work Package 5: Ancillary Benefits*

## Final Report

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## Contents

## Abstract

This report provides an analysis of the impact of global greenhouse gas policies on traditional air pollutants using the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model in the time horizon up to 2050. The integrated assessment framework of GAINS has been linked through an interface to the POLES global energy system model so that different global energy pathways can be implemented and examined. The impact analysis has been carried out based on projections of energy use data provided by the POLES model for two different climate policy scenarios, i.e., for a current policy Baseline scenario without any global greenhouse gas mitigation efforts, and a 2°C climate Mitigation scenario which assumes internationally coordinated action to mitigate climate change. Outcomes of the analysis are reported globally and for key world regions: EU-27, China, India and the US. The assessment takes into account current air pollution control legislation in each country.

The results of scenario calculations for $SO_2$, $NO_x$ and $PM_{2.5}$ emissions, air pollution control costs, as well as health and environmental impacts, indicate significant scope for co-benefits made possible through climate policies. Climate mitigation measures appear to be more effective in reducing oxides of sulphur and nitrogen, while emissions of particulate matter are reduced to a smaller extent. Decarbonisation of the global energy system by 2050 results in $SO_2$ and $NO_x$ emissions lower by two-thirds than in the world without GHG-abatement efforts. Corresponding reduction in the emissions of $PM_{2.5}$ is estimated at about 30% relative to the Baseline and is particularly sensitive to the assumptions on projected biomass combustion.

Expenditures on air pollution control under the global climate mitigation regime are reduced in 2050 by 250 billion € when compared to the Baseline scenario. Under the GAINS cost assumptions the largest potential for cost savings is reported for the transport sector, followed by savings in the power generation sector. Around one third of financial co-benefits estimated world-wide in this study by 2050 are allocated to China, while an annual cost saving of 35 billion € is estimated for the EU member countries if the current air pollution legislation and climate policies are adopted in parallel.

This study also quantifies health impacts of air pollution in Europe, China and India in terms of loss of life expectancy related to the exposure from anthropogenic emissions of $PM_{2.5}$, as well as in terms of premature mortality due to ground-level ozone. For example in China, current ambient concentrations of $PM_{2.5}$ are responsible for 38 months-losses in the average life expectancy. In 2050, the global GHG-mitigating strategies reduce this indicator in China by 16 months. In addition, decrease of ozone concentrations in the three regions as estimated for the climate Mitigation scenario in 2050 might save nearly 80,000 cases of premature death per year. Similarly significant are reductions of impacts on ecosystems due to acidification and eutrophication.

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# 1 Introduction

The European Commission (EC) has made proposals for keeping climate change to manageable levels in its Communication "Limiting Global Climate Change to 2° Celsius: The way ahead for 2020 and beyond" (EC, 2007). The Communication proposed ambitious emission reduction pathways for greenhouse gases (GHG) that the EU should pursue in the context of international climate change negotiations necessary to ensure that climate change does not cause temperatures to increase beyond 2°C. Modelling analysis of global climate policy scenarios for 2030 and beyond (Russ et al., 2007) has been performed in order to support the Commission's Communication.

To establish a coherent EU position ahead of the 2009 UN Climate Conference in Copenhagen (see http://unfccc.int/meetings/cop_15/items/5257.php), the European Commission has adopted the Communication titled “Towards a comprehensive climate change agreement in Copenhagen” (EC, 2009a). The Communication has been supported by modelling activities to assess the technological and economic effects of scenarios that can meet the EU 2°C target (Russ et al., 2009). In this context, the ClimateCost (the Full Costs of Climate Change) project (www.climatecost.cc) in one of its Work Packages explored co-benefits of combined climate change and air pollution policies.

This report describes results of detailed assessment of the air pollution impacts of future climate policies consistent with EU 2°C target for key individual countries and regions, covering all sectors responsible for emissions of anthropogenic greenhouse gases and air pollutants for the period after 2012, up to 2050. The target years of analyses are 2020, 2030, and 2050. Co-benefits in terms of control costs, physical impacts of air pollution (i.e. $SO_2$, $NO_x$, and $PM_{2.5}$) on human health and ecosystems have been estimated globally, as well as for Europe, China and India.

Work reported here involves the linkage of the global POLES energy-system model with GAINS (Greenhouse and Air pollution Interactions and Synergies model), which is a tool to quantify emission levels, costs and impacts of strategies to reduce both greenhouse gases and conventional air pollutants. Based on activity projections provided by POLES, emissions scenarios have been developed in GAINS considering a full implementation of current national legislation to control air pollution by 2030, but not strengthening it further between 2030 and 2050.

The report is organised as follows. Section 2 provides a description of the modelling tools and the methodology applied in models linkage. Section 3 discusses main assumptions underlying the scenarios and describes the time evolution of socio-economic parameters, as well as illustrating changes within the global energy system under climate mitigation regime. Section 4 summarises impacts of GHG-mitigation on air pollution, emission control costs, and on selected health and ecosystem indicators. Finally, conclusions and policy insights are presented in Section 5.

# 2 Modelling tools

In this study, information from two models, GAINS and POLES, is combined to quantify the impacts of long-term global GHG-mitigation efforts on air pollution emissions in key world regions, namely Europe, China, India and the US. The analysis considers emissions of $SO_2$, $NO_x$, and $PM_{2.5}$, and how the anticipated changes in future activity levels combined with progressive implementation of national emission control legislation will impact these emissions together with associated abatement costs, health and environmental impacts.

In practice, this task has been achieved by setting up a procedure to facilitate the transfer of activity projections from the global model POLES to the GAINS integrated assessment framework. By means of this interface it is possible for GAINS to assess the indirect impact of climate change mitigation policies on traditional local air pollution ($SO_2$, $NO_x$ and $PM_{2.5}$).

## 2.1 The GAINS model

The Greenhouse and Air pollution Interactions and Synergies (GAINS) model explores cost-effective strategies to reduce emissions of greenhouse gases (GHG) and conventional air pollutants. The GAINS model (http://gains.iiasa.ac.at) produces emission scenarios for all major air pollutants for any exogenously supplied projection of future economic activities, abatement potentials, and costs as well as interactions in abatement between various pollutants (Klaassen et al., 2004).

GAINS considers measures for the full range of precursor emissions that cause negative effects on human health via the exposure of fine particles and ground-level ozone, damage to vegetation via excess deposition of acidifying and eutrophying compounds, as well as the six greenhouse gases considered in the Kyoto protocol (Figure 1). In addition, it also assesses how specific mitigation measures simultaneously influence different pollutants. Thereby, GAINS allows for a comprehensive and combined analysis of air pollution and climate change mitigation strategies, which reveals important synergies and trade-offs between these policy areas.

| | PM | $SO_2$ | $NO_x$ | VOC | $NH_3$ | $CO_2$ | $CH_4$ | $N_2O$ | HFCs PFCs $SF_6$ |
|---|---|---|---|---|---|---|---|---|---|
| Health impacts: PM | √ | √ | √ | √ | √ | | | | |
| $O_3$ | | | √ | √ | | | √ | | |
| Vegetation damage: $O_3$ | | | √ | √ | | | √ | | |
| Acidification | | √ | √ | | √ | | | | |
| Eutrophication | | | √ | | √ | | | | |
| Radiative forcing: - direct | | | | | | √ | √ | √ | √ |
| - via aerosols | √ | √ | √ | √ | √ | | | | |
| - via OH | | | √ | √ | | | √ | | |

**Figure 1** The GAINS multi-pollutant/multi-effect framework.

The GAINS model is currently implemented globally on regional, national or provincial levels for 45 countries in Europe, for the Annex I countries of the Kyoto Protocol, for fast growing economies of

China and India, as well as for remaining countries in East and South Asia, Africa, Middle East and South America. It covers the time horizon up to 2050 in 5-years steps.

## 2.2 The POLES model

The underlying projections of energy activities that determine the levels of greenhouse gases and air pollution in a given scenario are provided by the global energy system model POLES (EC, 2006). The POLES (Prospective Outlook for the Long term Energy System) model is a world simulation model for the energy sector. It works in a year-by-year recursive simulation and partial equilibrium framework, with endogenous international energy prices and lagged adjustments of supply and demand by world region (detailed information available from the POLES web page http://energy.jrc.ec.europa.eu/Pages/Activities.htm#POLES).

The model is developed in the framework of a hierarchical structure of interconnected modules at the international, regional and national level. It contains technologically-detailed modules for energy-intensive sectors, including power generation, iron and steel, the chemical sector, aluminium production, cement making, non-ferrous minerals and modal transportation sectors (including aviation).

In each sector, energy consumption is calculated both for substitutable fuels and for electricity, taking into account specific energy consumption. Each demand equation has an income or activity variable elasticity, price elasticity, technological trends and, when appropriate, saturation effects. Particular attention is paid to the treatment of price effects. The world is broken down into 47 regions, for which the model delivers detailed energy balances.

All energy prices are determined endogenously in POLES. Oil prices in the long term depend primarily on the relative scarcity of oil reserves (i.e. the ratio of reserve to production). In the short run, the oil price is mainly influenced by spare production capacities of large oil producing countries (Russ et al., 2009).

## 2.3 Linkage of the GAINS and POLES models

In the GAINS model emissions of the pollutants that are examined in this report (i.e., $SO_2$, $NO_x$, $PM_{2.5}$) are calculated as the product of the energy activity levels, the “uncontrolled” emission factor in absence of any emission control measures, a factor adjusting for the efficiency of emission control measures and the application rate of such measures. The configuration of these parameters defines a “control strategy”, which reflects the level of implementation of emission abatement legislation and adoption of environmental standards. It is noted that the GAINS database contains information about hundreds of abatement technologies (or measures) in numerous sectors, applicable to a range of activities or energy carriers. Since the energy balances of POLES are more aggregated than those of GAINS, it is necessary to perform some form of aggregation in order to relate the POLES and GAINS structures to each other.

In a previous exercise (Rafaj et al., 2009) abated emission factors, calculated from recent control strategies reflecting current national legislation, were used for this purpose. Abated emission factors were derived from existing GAINS emission scenarios by dividing the calculated emissions by the corresponding activities. These abated emission factors were calculated for the respective sector-fuel combinations as supplied by POLES and then used to estimate air pollutant emissions from the

POLES data. In the present work, however, the POLES energy projections and economic activity pathways were implemented directly in GAINS, necessitating the relationships between the POLES and GAINS model structures to be determined in terms of:

- regional structure,
- activities and sectors.

The mapping of POLES to GAINS regions is provided in Appendix I.

Appendix II shows the mapping between the activity and sector combinations used in the two models. Essentially this indicates which GAINS activity-sector combinations had to be aggregated in order to translate POLES activity levels to the GAINS structure.

The resulting ratio between the POLES activity and the corresponding aggregated GAINS activity was then used to scale the existing GAINS activities, providing 'POLES' activity levels for all relevant GAINS activities and sectors.

$$A'_y = A_y \cdot f$$

where

$A'_y$ is the 'POLES' activity in GAINS structure in year $y$

$A_y$ is the GAINS activity in year $y$

and the factor $f$ is taken to be the minimum of:

$$f = \frac{P_y}{G_y}$$

and

$$f = \frac{P_y}{G_y} \cdot \frac{G_{2005}}{P_{2005}}$$

where

$P_y$ is the POLES activity in year $y$

$G_y$ is the aggregated GAINS activity in POLES structure in year $y$

The scaling algorithm also assures that the resulting energy projections adopted in GAINS correspond to overall primary energy consumption of the main energy carriers as modelled in POLES. The model interface has been implemented as a set of database queries that provide a consistent and efficient means of repeating the model linkage whenever required. Although the POLES inputs provide information on the time evolution of the energy sector until 2050, there is a set of emission sources not covered directly by the energy model. Missing information has therefore been completed based on scenarios already available in GAINS or has been derived from relevant drivers, for example, GDP and population projections. In particular, this included derivation of sector-specific data for transport (vehicle-kilometres, vehicle numbers) and estimation of activities causing process emissions (production of energy-intensive products, agricultural activities, storage and handling of materials, waste treatment, etc.). Projections of activities for the process sector have been based on national statistics, however, for all countries no changes in production structure of energy-intensive commodities and no shift from industrialised countries to the developing world was assumed.

# 3 Scenarios

Using the procedure outlined above provides a GAINS implementation of a POLES scenario that can be used for emission, cost and impact calculations. The data translation has been performed for two POLES scenarios, allowing the impact of climate change mitigation policies on traditional air pollutants to be assessed:

- **Baseline scenario** that reflects unchanged governmental energy and climate policies, and
- **Mitigation scenario** which assumes implementation of policies to limit the increase in average global temperatures to about 2°C.

Both scenarios were developed in the course of analyses carried out and presented in this report. Scenarios represent versions as of June 2011 and are consistent with analyses performed to support the EC's Communications. Underlying drivers and assumptions behind the POLES energy projections summarised below are described in detail by Russ et al. (2009).

## 3.1 Baseline scenario

The Baseline scenario explores a pessimistic situation in which no further climate and air pollution policies are implemented beyond what was in place in the year 2010. This means that energy consumption from 2010 to 2050 is driven by population and economic growth (see Figure 2) but not by energy efficiency/climate change policies. The Baseline scenario takes into account the existence of the emission trading scheme (ETS) market in the EU and the prospect of future climate policies in other countries, the consequences of the financial crisis in 2008/2009, and the evolution of the oil prices. In the Baseline, the carbon price in the EU-ETS starts at 20 €/t$CO_2$ in 2010 and increases linearly to 24 €/t$CO_2$ in 2030 and beyond. However, the Baseline for the EU used for the present assessment includes neither the implementation of the unilateral GHG reduction target (20% compared to 1990 by 2020) nor the renewables target (20% by 2020) as proposed in the EU energy and climate change package (EC, 2008). Therefore the Baseline used in the present analysis does not include the outcome of the approved policy changes under the adopted climate change and energy package.

In the other developed countries a 5 €/t$CO_2$ carbon price is included for the same sectors as those included in the EU's ETS. This aims to simulate the fact that also in developed countries that presently lack ambitious climate change policies, investment decisions are already influenced by the prospect of future mitigation policies. Oil prices in the Baseline scenario are projected to reach 78 US$/bl in 2020, 96 US$/bl in 2030 and 138 US$/bl in 2050 (in 2005 prices).

In the Baseline between 2005 and 2050, average yearly GDP growth is 1.7% for developed countries and 4.4% for developing countries, resulting in a yearly average global growth of 2.7%. The Baseline takes into account the current financial crisis. The growth projections were adapted when the deterioration of growth prospects became obvious in autumn 2008. Growth rates were reduced for the main regions for the coming 2 years using the then most recent IMF economic forecasts (IMF, 2008). Afterwards, it is assumed that growth will return to higher levels. The population projections are consistent with the UN World Population Outlooks (http://esa.un.org/unpd/wpp/index.htm) and assume an annual growth of 0.8% globally between 2005 and 2050. In absolute terms, the world population is expected to increase from the current 6.5 billion to about 9.2 billion people in 2050.

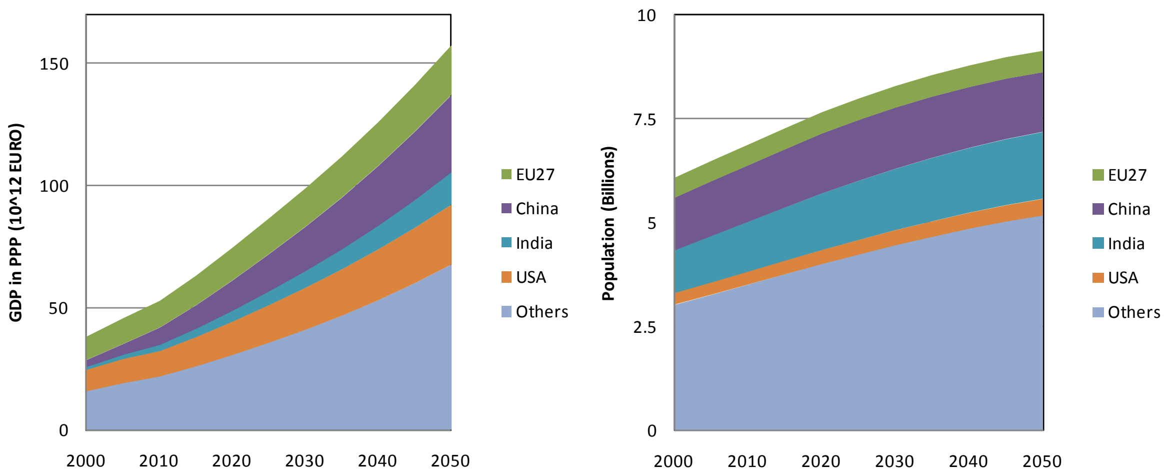


**Figure 2** GDP and population projections in the Baseline scenario by regions. Source: POLES.

## 3.2 Mitigation scenario

The Mitigation scenario provided by the POLES model is a greenhouse gas reduction scenario with global $CO_2$ emissions reduced by 60% in 2050 compared to 1990. These reductions, together with those in agriculture and in land-use change and forestry (de-forestation), would contribute to achieving a global mean temperature increase of less than 2 degrees above its pre-industrial value (Russ et al, 2007). The Mitigation scenario explored in this analysis corresponds to the updated version of the 'Central scenario' belonging to the group of global climate policy cases defined by Russ el al. (2009). The Mitigation scenario simultaneously takes into account four main indicators responsible for emission changes: GDP/capita, GHG/GDP, GHG emission trends and population trends. Each developed country has intermediate targets which lie between the extremes of the single-indicator targets. For the developing countries it was assumed that they would also introduce internal actions to ensure global emissions are on a pathway to stay within the 2ºC objective. In order to determine the level of action by developing countries in this scenario, similar indicators were used as for developed countries.

Developed countries take on a collective emission reduction target and they set up a trading system such as the EU ETS or similar policy measures that establish a carbon price for the energy intensive industrial sectors, including the power sector. A carbon market exists for the sectors included in the EU ETS but it is not perfect and the effective carbon prices are assumed to vary between the various regions in the world because of differences in transaction costs and they converge over time. Energy intensive sectors in developing countries are exposed to a low carbon price in 2012, simulating the limited penetration or visibility of a carbon price for all individual firms through policy instruments such as the CDM. However, between 2025 and 2030, differences in carbon prices become relatively smaller for all groups of countries apart from low income countries (Russ et al., 2009). Further details on assumptions behind the climate policies adopted in the Mitigation scenario are described in EC (2009b).

Macroeconomic projections in the Mitigation scenario by 2050 do not differ from those assumed in the Baseline. However, because of the demand reductions induced by carbon tax on fossil fuels, oil prices in the Mitigation scenario decreased relative to the Baseline and reach levels of 74 US$/bl in 2020, 77 US$/bl in 2030 and 69 US$/bl in 2050.

## 3.3 Changes in energy consumption

Calculation of emissions by GAINS is based on projections of the economic activities that cover the energy sector, industrial processes, and agriculture. Activity projections from POLES that are used in this analysis comprise the energy sector and steel production. Some activities relevant for emission calculation, which are not included in the POLES input, e.g., the energy transformation sector or industrial processes, are derived from the GAINS data using general trends from POLES. The final use of energy as well as the fuel mix for electricity production is provided, however, explicit technology mixes for power supply or transport services are distinguished for the Baseline and Mitigation scenarios based on additional information used in disaggregating POLES data into the GAINS structure, as described in Section 2.3.

Because of different mitigation costs and abatement potentials, the resulting cuts in GHG emissions differ largely across regions. The underlying structural changes in the national and regional energy systems differ too, as illustrated in Figure 3 - Figure 7, showing the evolution of the fuel mix globally, in EU-27, China, India and USA, for both the Baseline and Mitigation scenarios. In the figures presented here, liquid biofuels used in the transport sector are included in oil, assuming similar emission factors for the combustion of biofuels and oil products.

At both the global and regional levels, coal undergoes the largest reduction in the climate-policy scenario when compared to the Baseline. Reduction in the use of coal is significant in spite of rapid introduction of carbon capture systems in the power sector. For example, in China the use of coal drops by 50% in 2030 and by 75% in 2050, relative to the Baseline. Other fossil fuels, i.e., oil products and gas, are reduced in 2050 by a smaller extent, 60% and 40%, respectively. Consumption of solid biomass, renewables and nuclear power increases significantly over the Baseline levels. Although not seen from Figure 3 - Figure 7, the substantial reductions in the use of fossil fuels are further balanced by the growth in energy efficiency, as well as by demand reductions.

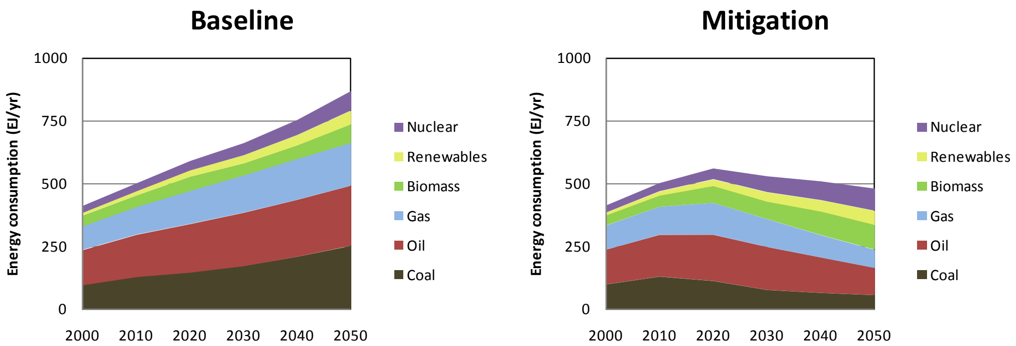


**Figure 3** Global energy consumption by fuels in the Baseline and Mitigation scenarios. Source: POLES.

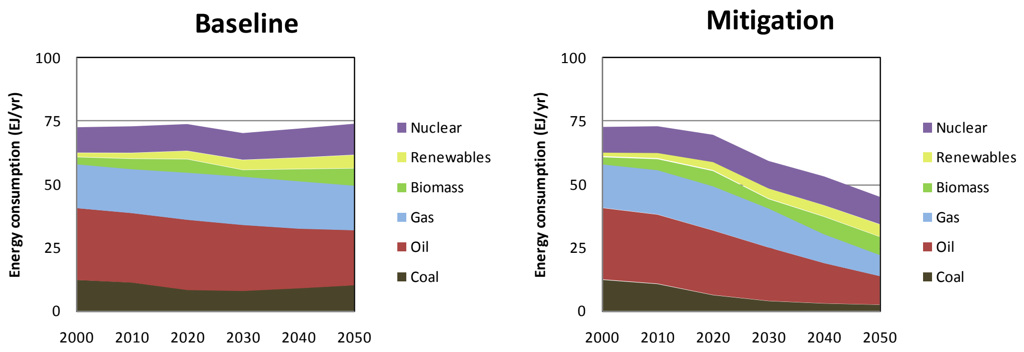


**Figure 4** Energy consumption by fuels in the Baseline and Mitigation scenarios in EU-27. Source: POLES.

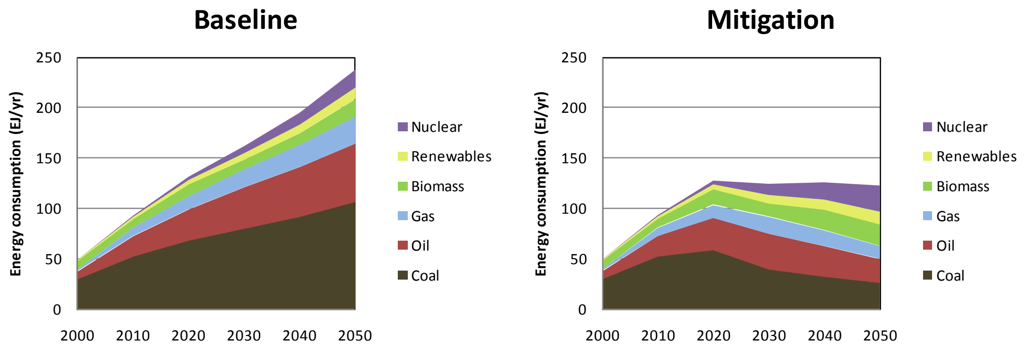


**Figure 5** Energy consumption by fuels in the Baseline and Mitigation scenarios in China. Source: POLES.

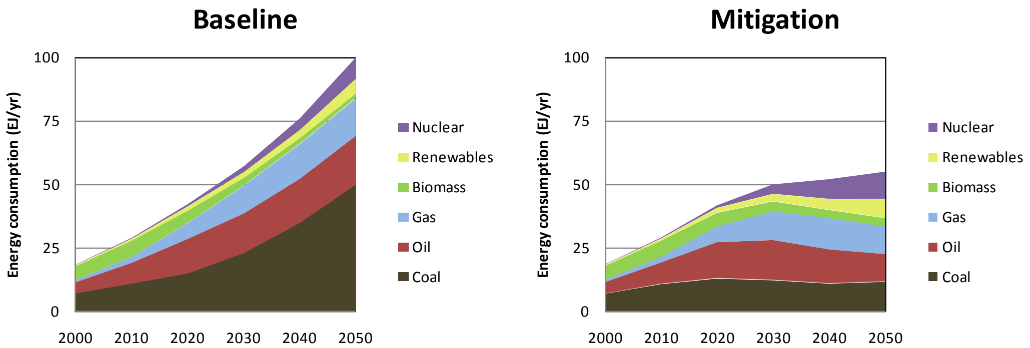


**Figure 6** Energy consumption by fuels in the Baseline and Mitigation scenarios in India. Source: POLES.

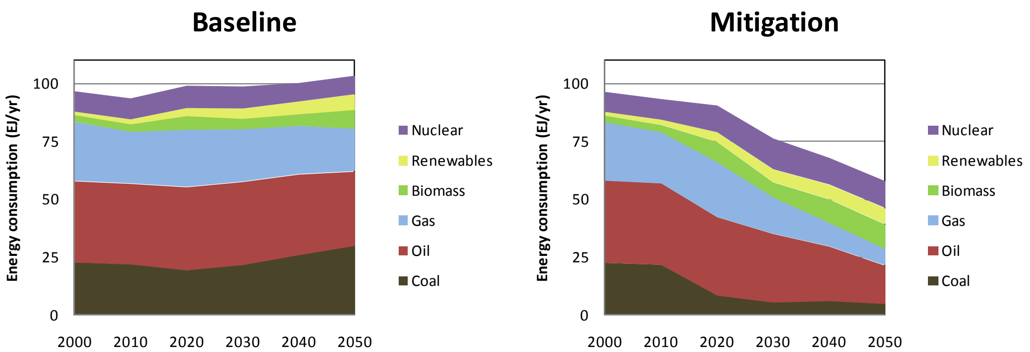


**Figure 7** Energy consumption by fuels in the Baseline and Mitigation scenarios in USA. Source: POLES.

## 3.4 Air pollution control

Control strategies used for calculation of global emissions are based on the most recent national legislation and environmental planning, i.e., policies that were in force or in the final stage of legislative process as of 2010 (Cofala et al., 2010). In particular, for Europe all emission limit values and fuel quality standards have been included, as used in the analysis for the revision of the National Emission Ceilings (NEC) Directive (Amann et al., 2008). For other countries policies have been assessed based on available literature (compare Cofala et al., 2007). They take into account recent updates done in collaboration with national expert teams (Klimont et al., 2009). In addition, assumptions about emission controls in the power plant sector have been cross-checked with detailed information from the database on world coal-fired power plants (IEA CCC, 2010). An important role in air pollution abatement is played by controlling emissions from mobile sources. Again, for Europe the same assumptions have been made as for the modelling work for the revision of the NEC Directive. For other countries information from DieselNet (2010) and national sources was used.

The temporal penetration of emission-abatement measures until 2030 in selected representative countries in industrialised and developing world for mobile and stationary sources is shown in Table 1 to Table 5.

**Table 1** Implementation of different stages of EURO-standards for light-duty and heavy-duty vehicles.

| COUNTRY | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| EU | EURO-2/II | EURO-3/III | EURO-4/IV | EURO-5/V | EURO-6/VI | EURO-6/VI | EURO-6/VI |
| JAPAN | EURO-2/II | EURO-3/III | EURO-4/IV | EURO-5/V | EURO-6/VI | EURO-6/VI | EURO-6/VI |
| USA | EURO-2/II | EURO-3/III | EURO-4/IV | EURO-5/V | EURO-6/VI | EURO-6/VI | EURO-6/VI |
| RUSSIA | | EURO-2/II | EURO-3/III | EURO-4/IV | EURO-4/IV | EURO-4/IV | EURO-4/IV |
| CHINA | EURO-1/I | EURO-2/II | EURO-3/III | EURO-4/IV | EURO-4/IV | EURO-4/IV | EURO-4/IV |
| INDIA | EURO-1/I | EURO-2/II | EURO-3/III | EURO-3/III | EURO-4/IV | EURO-4/IV | EURO-4/IV |
| BRAZIL | EURO-1/I | EURO-2/II | EURO-3/III | EURO-3/III | EURO-3/III | EURO-3/III | EURO-3/III |
| INDONESIA | | EURO-2/II | EURO-2/II | EURO-2/II | EURO-2/II | EURO-2/II | EURO-2/II |

**Table 2** Fuel quality standards for maximal sulphur content in automotive fuels. Ppm is parts per million by volume.

| COUNTRY | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| EU | 450 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm |
| JAPAN | 450 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm |
| USA | 450 ppm | 450 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm |
| RUSSIA | 2000 ppm | 450 ppm | 450 ppm | 450 ppm | 450 ppm | 450 ppm | 450 ppm |
| CHINA | 2000 ppm | 2000 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm |
| INDIA | 2000 ppm | 450 ppm | 450 ppm | 10 ppm | 10 ppm | 10 ppm | 10 ppm |
| BRAZIL | 450 ppm | 450 ppm | 450 ppm | 450 ppm | 10 ppm | 10 ppm | 10 ppm |
| INDONESIA | | | | | | | |

**Table 3** Projected use of measures to reduce $NO_x$ emissions from stationary sources. CM is combustion modification. SCR is selective catalytic reduction.

| COUNTRY | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| EU | CM | CM/SCR | SCR | SCR | SCR | SCR | SCR |
| JAPAN | CM/SCR | CM/SCR | SCR | SCR | SCR | SCR | SCR |
| USA | CM | CM/SCR | CM/SCR | SCR | SCR | SCR | SCR |
| RUSSIA | | | CM | CM | CM | CM | CM |
| CHINA | | | CM | CM | CM | CM | CM |
| INDIA | | | CM | CM | CM | CM | CM |
| BRAZIL | | | CM | CM | CM | CM | CM |
| INDONESIA | | | CM | CM | CM | CM | CM |

**Table 4** Projected use of measures to reduce $SO_2$ emissions from stationary sources. FGD is flue gas desulphurization (full or partial adoption).

| COUNTRY | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| EU | FGD | FGD | FGD | FGD | FGD | FGD | FGD |
| JAPAN | FGD | FGD | FGD | FGD | FGD | FGD | FGD |
| USA | FGD-part | FGD-part | FGD | FGD | FGD | FGD | FGD |
| RUSSIA | | | FGD-part | FGD-part | FGD-part | FGD-part | FGD-part |
| CHINA | low S coal | low S coal | FGD-part | FGD-part | FGD-part | FGD-part | FGD-part |
| INDIA | | | | | | | |
| BRAZIL | FGD-part | FGD-part | FGD-part | FGD-part | FGD-part | FGD-part | FGD-part |
| INDONESIA | FGD-part | FGD-part | FGD-part | FGD-part | FGD-part | FGD-part | FGD-part |

**Table 5** Projected use of measures to reduce $PM_{2.5}$ emissions from stationary sources. CYC is cyclone. ESP1 is Electrostatic precipitator: 1 field. ESP2 is Electrostatic precipitator: 2 fields. HED is high efficiency de-duster.

| COUNTRY | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| EU | ESP2 | ESP2 | HED | HED | HED | HED | HED |
| JAPAN | ESP2 | HED | HED | HED | HED | HED | HED |
| USA | ESP1 | ESP2 | HED | HED | HED | HED | HED |
| RUSSIA | ESP1 | ESP1 | ESP1 | ESP1 | ESP2 | ESP2 | ESP2 |
| CHINA | CYC | ESP1 | ESP1 | ESP1 | ESP1 | ESP2 | ESP2 |
| INDIA | CYC | ESP1 | ESP1 | ESP2 | ESP2 | ESP2 | ESP2 |
| BRAZIL | CYC | ESP1 | ESP1 | ESP1 | ESP2 | ESP2 | ESP2 |
| INDONESIA | CYC | ESP1 | ESP1 | ESP1 | ESP1 | ESP2 | ESP2 |

In the above tables, emission control measures are indicated for the period until the year 2030, i.e., the latest year for which GAINS provides detailed information on the current abatement legislation. The question, however, how such emission factors will change in the long run after 2030, cannot be answered in an unambiguous way as it is influenced by the rate of technological progress on emission control measures and intentional changes in national air quality legislation.

While a wide range of developments is conceivable, a conservative assumption that technologies and legislation would not change beyond 2030 has been adopted in the emission calculations reported herein. The current legislation (CLE) approach for defining assumptions on emission control by 2050 assumes no autonomous change of end-of-pipe control measures beyond the status adopted in 2030. Obviously, this case defines an upper range of emission projections (compare with Rafaj et al. (2010)).

Finally, it is emphasised that the co-benefits of GHG mitigation policies for air quality emerge solely from the reconfiguration of the energy system, and not from more stringent air pollution emission control measures under a climate protection regime.

# 4 Results

The POLES energy scenarios have been implemented in the GAINS model for the full set of regions included in GAINS (see Appendix III), which covers the whole world. In some cases GAINS regions represent the sub-national level (e.g. for India and China), in others individual countries, and still others as country groups. Emissions and costs can be quantified not only globally but for each of these regions separately, if required. For the purpose of illustration, the following sections explore the emissions and costs globally, as well as for four regions representing major emitters, viz, the EU-27, China, India and the United States. The quantification of physical impacts is reported for three regions: the EU-27, China and India.

## 4.1 Impacts on $CO_2$ emissions

Figure 8 illustrates impacts of climate policy targets on the reduction of $CO_2$ emissions by 2050. Globally, $CO_2$ emissions decrease by 13%, 40% and 80% as compared to the Baseline emission levels in 2020, 2030 and 2050. While reductions in developing regions (China and India) are marginal by 2020, it is assumed that early emission cuts are achieved in industrialised countries: 12% and 23% in EU-27 and in the US, respectively. By 2050, both China and India adopt stringent GHG mitigation policies, which results in significant $CO_2$ reductions at a range of 80% relative to the Baseline scenario. The largest contribution to emission reductions in all regions is observed in the power sector, followed by combustion in manufacturing industry and in the transport sector.

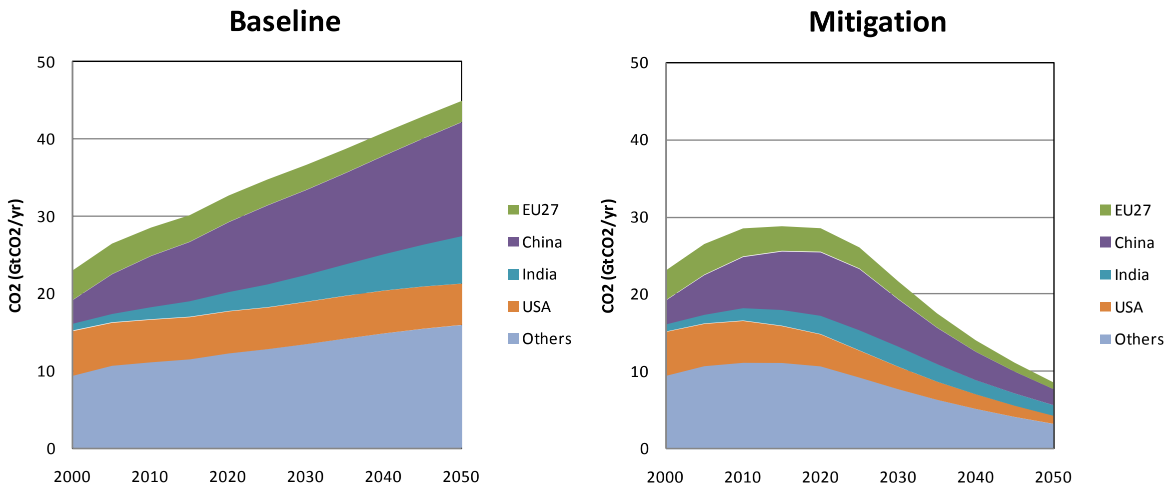


**Figure 8** $CO_2$ emissions of the Baseline and Mitigation scenarios by regions. Source: POLES.

## 4.2 Impacts on emissions of air pollutants and control costs

The linkage established between the GAINS and POLES models results in trajectories for air pollutants that combine short-term air pollution control policies with the long-term evolution of the global energy system driven by the climate mitigation objectives. Global emission estimates of $SO_2$, $NO_x$ and $PM_{2.5}$ for the Baseline and Mitigation scenarios for the period 2005 – 2050 are compared in Figure 9. Globally, some reduction in emissions between the two scenarios is apparent by 2020 but this is relatively small (11 % for $SO_2$, 7 % for $NO_x$). In 2030 the change is more pronounced, with 40% less $SO_2$ emitted, 30% less $NO_x$ and a reduction in $PM_{2.5}$ emissions of 5%. In 2050, sulphur emissions are reduced by nearly 80 Mt $SO_2$ per annum; $NO_x$ is reduced by 53 Mt/yr and $PM_{2.5}$ by 11 Mt/yr, which corresponds to relative reductions over the Baseline of 70%, 60% and 30%, respectively.

The largest relative reductions in emissions are achieved in the power plant sector, with about 85% less air emissions in 2050, related to the much reduced use of coal in the Mitigation scenario. There are also significant reductions of 60% from households and industry for $SO_2$ and $NO_x$, while $PM_{2.5}$ and $NO_x$ emissions from transport are halved in comparison to the Baseline levels in 2050.

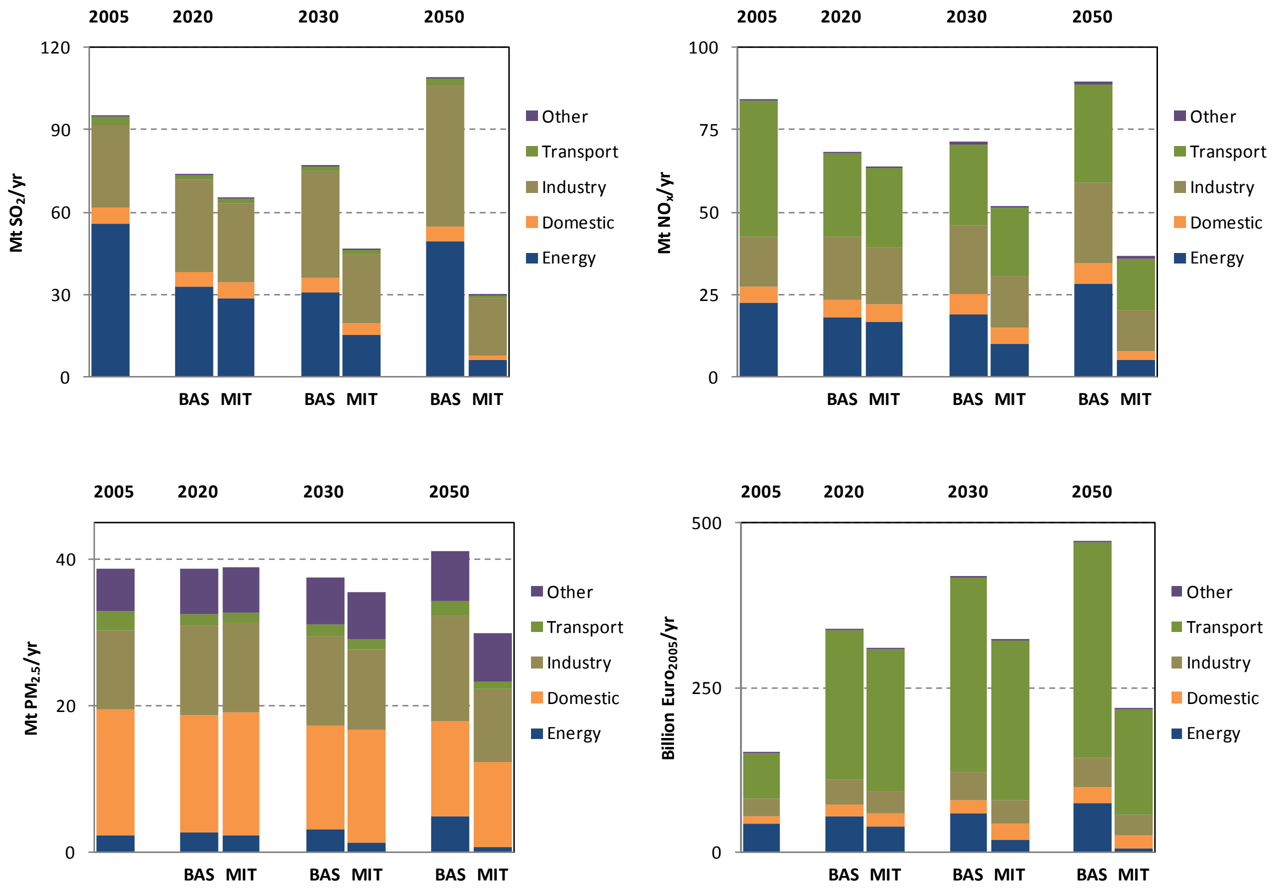


**Figure 9** Global emission estimates of $SO_2$ (top left panel), $NO_x$ (top right panel) and $PM_{2.5}$ (low left panel) for the Baseline (BAS) and Mitigation (MIT) scenarios for the period 2005 – 2050; Global air pollution control costs by scenarios and by sectors (low right panel).

Besides the considerable environmental impacts, carbon mitigation policies can have significant economic side-benefits in the form of savings from implementing air pollution measures that are required by legislation. Such financial co-benefits imply that an alternative energy planning would reduce costs for air pollution abatement because of the lower demand for fossil fuels, which in turn involve fewer installations of air-pollution control equipment.

Under the GAINS cost assumptions and using a 4% discount rate, global control costs for $SO_2$, $NO_x$ and $PM_{2.5}$ (i.e., the sum of costs of all world regions/countries defined in GAINS as listed in Appendix III) were about 152 billion €/a in 2005. Until 2050 these costs increase in the Baseline scenario by a factor of three, which is due to higher activity levels (e.g., higher energy consumption, higher car ownership) and increasing stringency of controls. In 2050, about 70 % of the total abatement expenditures are the costs of reducing the Baseline emissions from road transport sources. The climate policy scenario brings 22% cost savings in 2030 and 54% less costs in 2050 compared with the Baseline. In 2050, the annual savings incurred globally through the GHG mitigation policies are more than 250 billion Euros. The most affected is the power sector with cost reduction of 93%, followed by the transport sector, where the control cost is halved in 2050, relative to the Baseline. Co-benefits in terms of global reduction in air pollution control costs in the Baseline and in the Mitigation scenarios by major sectors are summarised in Figure 9.

### *4.2.1 EU-27*

Sizeable emission reductions in EU-27 Member States are expected already in the Baseline scenario as a result of changing fuel mix and consumption patterns, combined with implementation of current air quality legislation. A 72 % reduction in $SO_2$ emissions is expected between 2005 and 2050, while a drop by 45% is projected for $PM_{2.5}$ for the same period of time. Reduced consumption of fossil fuels in the Mitigation scenario leads, however, to even lower emissions of air pollutants to the atmosphere. Figure 10 compares the estimated emissions of $SO_2$, $NO_x$ and $PM_{2.5}$ in the EU-27 for the two scenarios for the period 2005 – 2050. Here the $SO_2$ emissions in the climate scenario are estimated to be 60% lower than in the Baseline in 2030, with the largest reductions from the power sector and industry. $NO_x$ emissions in 2050 are 46% lower in the climate scenario than in the Baseline, with the largest relative reductions in the power sector and in industry. Transport-related $NO_x$ emissions are reduced by 40%. The less carbon-intensive energy use structure in the climate scenario also leads to lower emissions of particulate matter. However, the emission reduction of -20% is less than for $SO_2$ and $NO_x$ due to increased combustion of biomass.

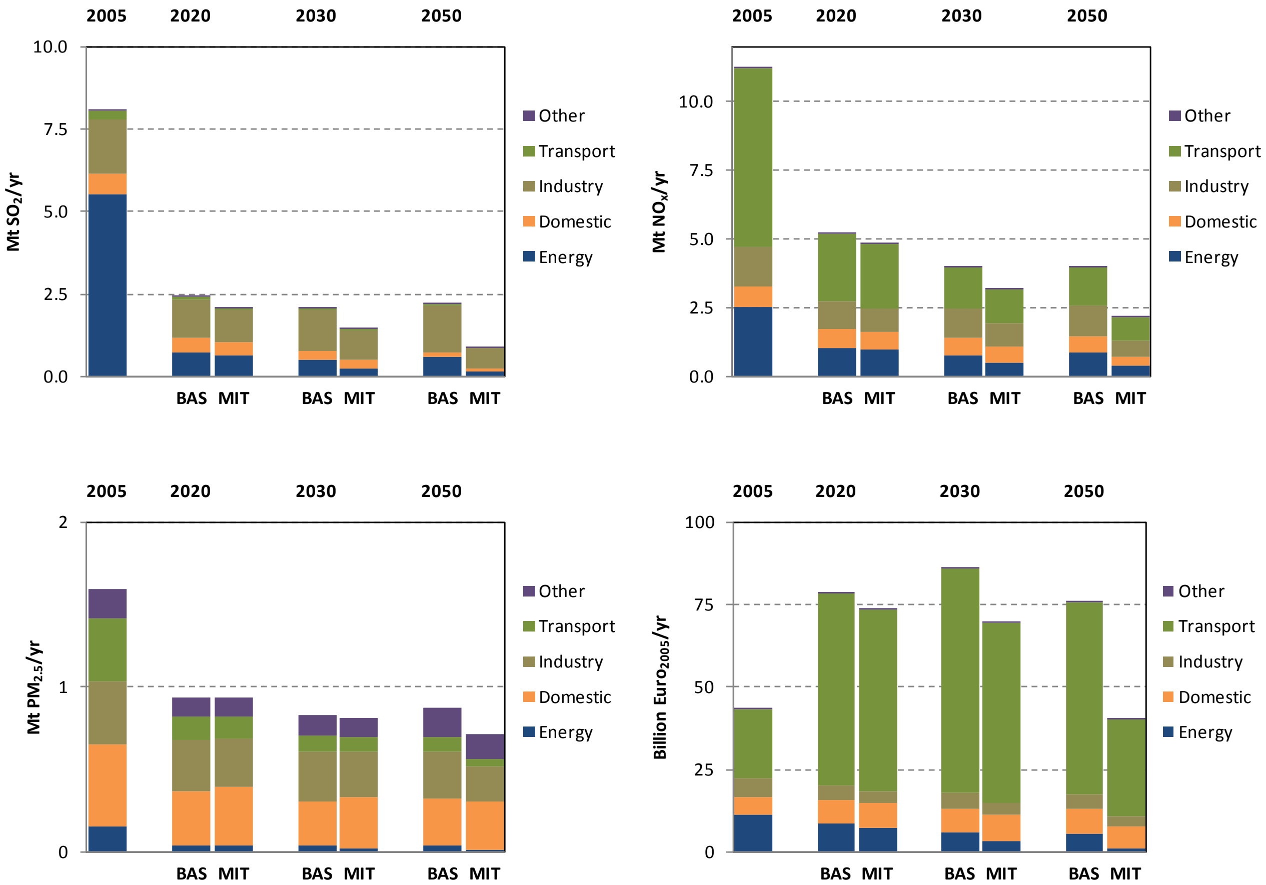


**Figure 10** EU-27: Emission estimates of $SO_2$ (top left panel), $NO_x$ (top right panel) and $PM_{2.5}$ (low left panel) for the Baseline (BAS) and Mitigation (MIT) scenarios for the period 2005 – 2050; Air pollution control costs by scenarios and by sectors (low right panel).

Costs of implementation of the current legislation within EU until 2050 are estimated at about 76 billion €$_{2005}$ per year (see Figure 10). The GAINS calculation suggests that this cost can be halved by 2050, if the climate targets assumed in the Mitigation scenarios are met. By 2050, the largest contribution to the cost savings of 35 billion €$_{2005}$ emerges in the EU-transport sector and amounts to about 80% of the total cost reduction. Estimates of air pollution emission and control costs by individual EU member countries are provided in Table A 1 and Table A 4 in Annexes.

### 4.2.2 China

Chinese emissions of $SO_2$, $NO_x$ and $PM_{2.5}$ for the Baseline and Mitigation scenarios for the period 2005 – 2050 are compared in Figure 11. In 2020 the overall difference in emissions of air pollutants between the two scenarios is negligible. By 2030, however, emissions of $SO_2$ are expected to be 42% lower in the climate scenario than in the Baseline, with corresponding reductions in $NO_x$ and $PM_{2.5}$ emissions of 36% and 16%, respectively. The synergetic effect of GHG abatement towards air pollution in 2050 invokes further Chinese emission reductions by 75% for $SO_2$, 70% for $NO_x$, and 40% for $PM_{2.5}$ in comparison to the Baseline projections. For all pollutants in question, the power sector benefits the most from climate policies, showing substantial emission reductions of around 90%.

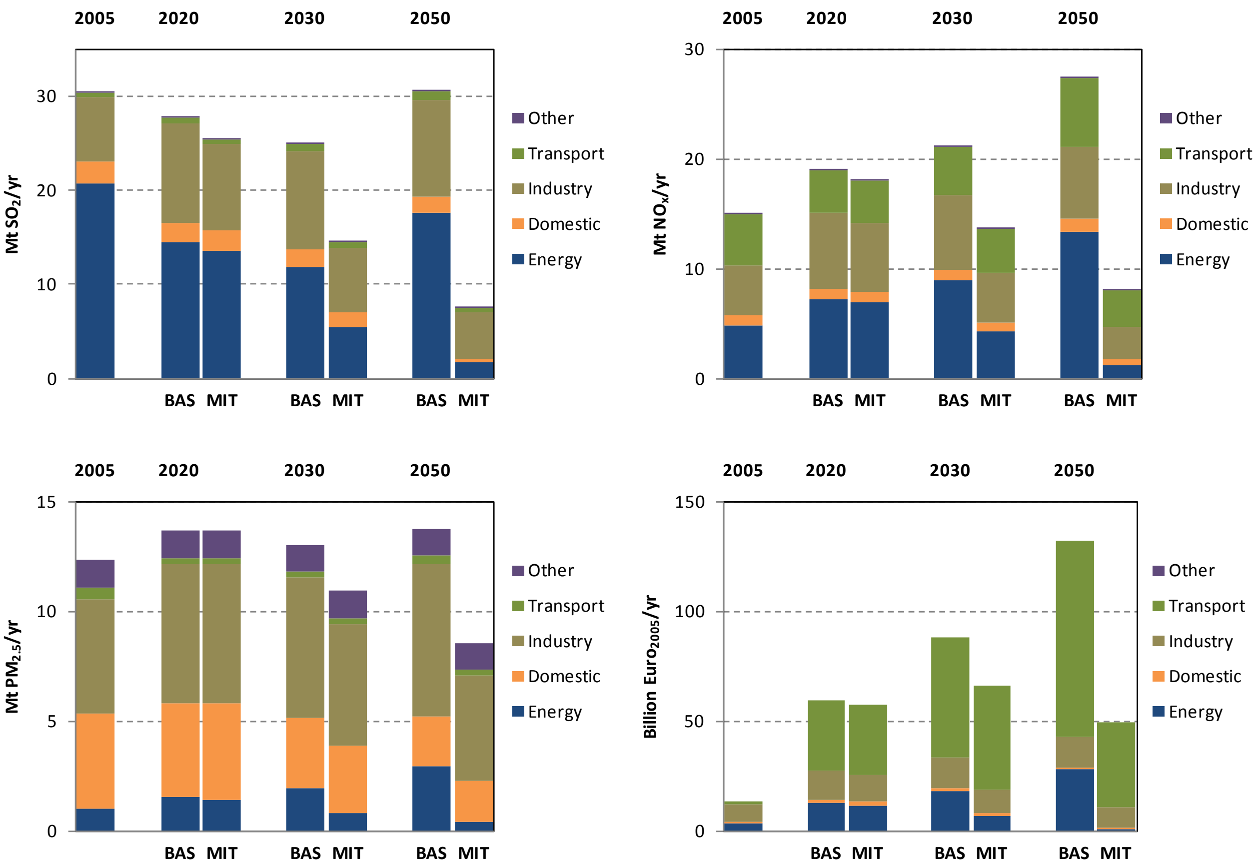


**Figure 11** China: Emission estimates of $SO_2$ (top left panel), $NO_x$ (top right panel) and $PM_{2.5}$ (low left panel) for the Baseline (BAS) and Mitigation (MIT) scenarios for the period 2005 – 2050; Air pollution control costs by scenarios and by sectors (low right panel).

An adoption of current legislation planned in China for improving air quality by 2050 would result in costs ten times higher than costs spent in 2005. The potential for savings through structural changes induced by climate policies up to 2050 is estimated at 83 billion €$_{2005}$. Contribution of the power sector to the overall cost savings in China is marginal by 2020. By 2030, however, the savings associated with the rapid fuel switching away from fossil fuels, in particular from coal, increases the cost-reduction share of the Chinese power sector to 50%. Until 2050, the overall cost reduction is dominated by the share of road transport, where the annual contribution to savings are quantified at 50 billion €$_{2005}$. Estimates of air pollution emission and control costs by individual provinces in China are provided in Table A 2 and Table A 4 in Annexes.

### 4.2.3 India

Figure 12 compares the estimated emissions of $SO_2$, $NO_x$ and $PM_{2.5}$ in India for the two scenarios for the period 2005 – 2050. Again, the overall difference in emissions of air pollutants between the two scenarios is small in 2020. By 2030 emissions of $SO_2$ are expected to be 27% lower in the Mitigation scenario than in the Baseline, with the largest decreases occurring in the power sector and in industry. The corresponding reductions in $NO_x$ and $PM_{2.5}$ emissions are 23% and 14%, respectively. By 2050, emission reductions are substantial, whereas particularly the power sector and industry contribute to the overall sulphur and $NO_x$ emissions drop. Especially important for the Indian air quality is the reduction of $PM_{2.5}$ emitted in the domestic sector by 1.3 Mt $PM_{2.5}$, or -73% per year, when compared to the Baseline projections up to 2050.

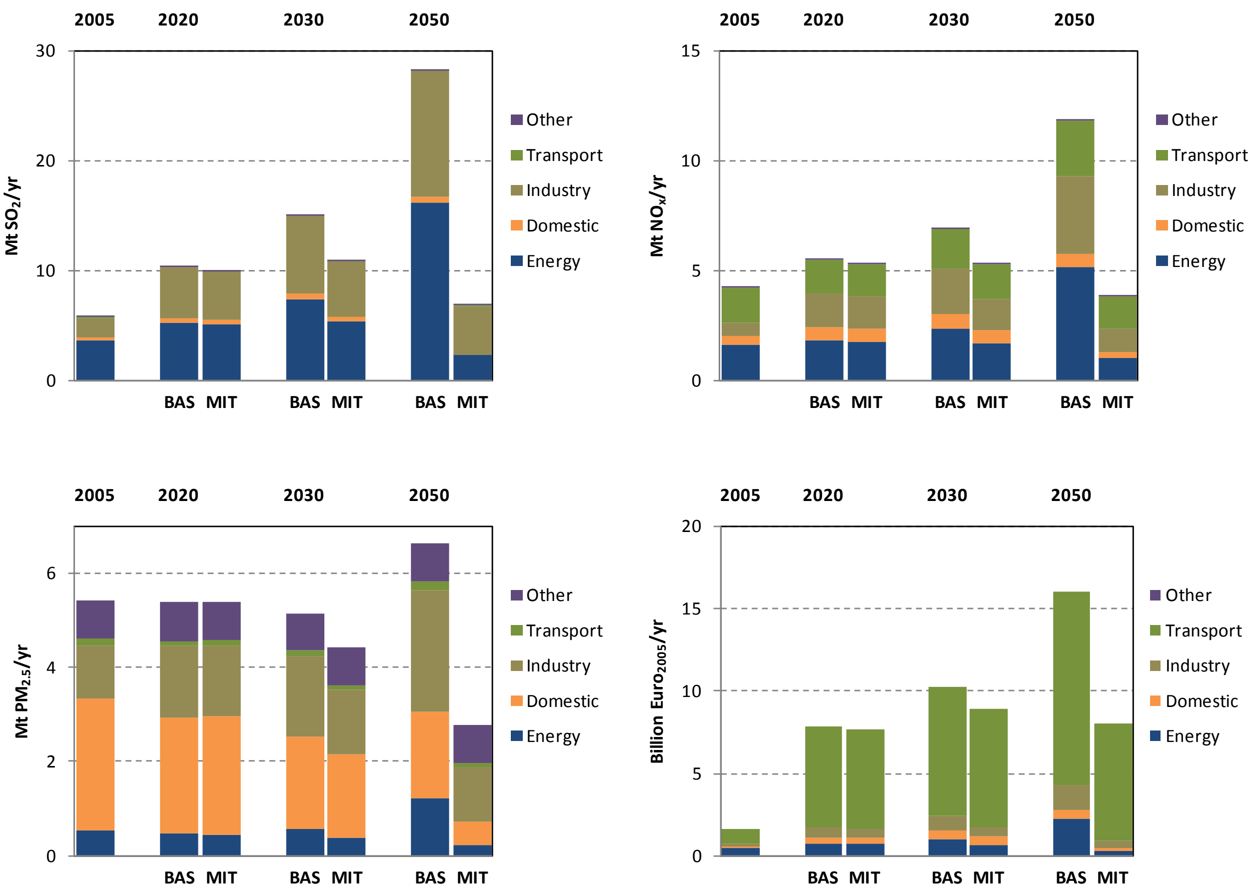


**Figure 12** India: Emission estimates of $SO_2$ (top left panel), $NO_x$ (top right panel) and $PM_{2.5}$ (low left panel) for the Baseline (BAS) and Mitigation (MIT) scenarios for the period 2005 – 2050; Air pollution control costs by scenarios and by sectors (low right panel).

Expressed in monetary terms, savings from an adoption of climate polices in India amounts to 8 billion €$_{2005}$/yr in 2050. In other words, GHG mitigation results in halving expenditures projected for an implementation of current air pollution legislation. Similarly to China, the power sector contributes to the overall cost savings in India only in the second half of the computation period. By 2050, the cost savings in the power sector reach about 25% of the total reduction in costs. The largest share of about 60% in the overall cost reduction in the Mitigation scenario is allocated to the transport sector. Estimates of air pollution emission and control costs by individual Indian states are provided in Table A 3 and Table A 4 in Annexes.

### 4.2.4 United States

On top of the 8 Mt of reduction in $SO_2$ emissions estimated in the Baseline scenario between 2005 and 2050, the Mitigation scenario indicates that $SO_2$ emissions will be 70% lower than in the Baseline in 2050, with most of the decreases coming from power plants and industry. Emissions of $NO_x$ are 56% lower in the Mitigation scenario in 2050, and the corresponding overall decrease for $PM_{2.5}$ is 23%. The largest reduction in $PM_{2.5}$ emissions is observed in the domestic sector. An increase in the US's emissions of particulate matter relative to the Baseline is reported for the period 2020 to 2030, which is associated with the assumptions on biomass combustion in the domestic sector. Emission profiles of $SO_2$, $NO_x$ and $PM_{2.5}$ from the United States for the Baseline and Mitigation scenarios for the period 2005 – 2050 are compared in Figure 13.

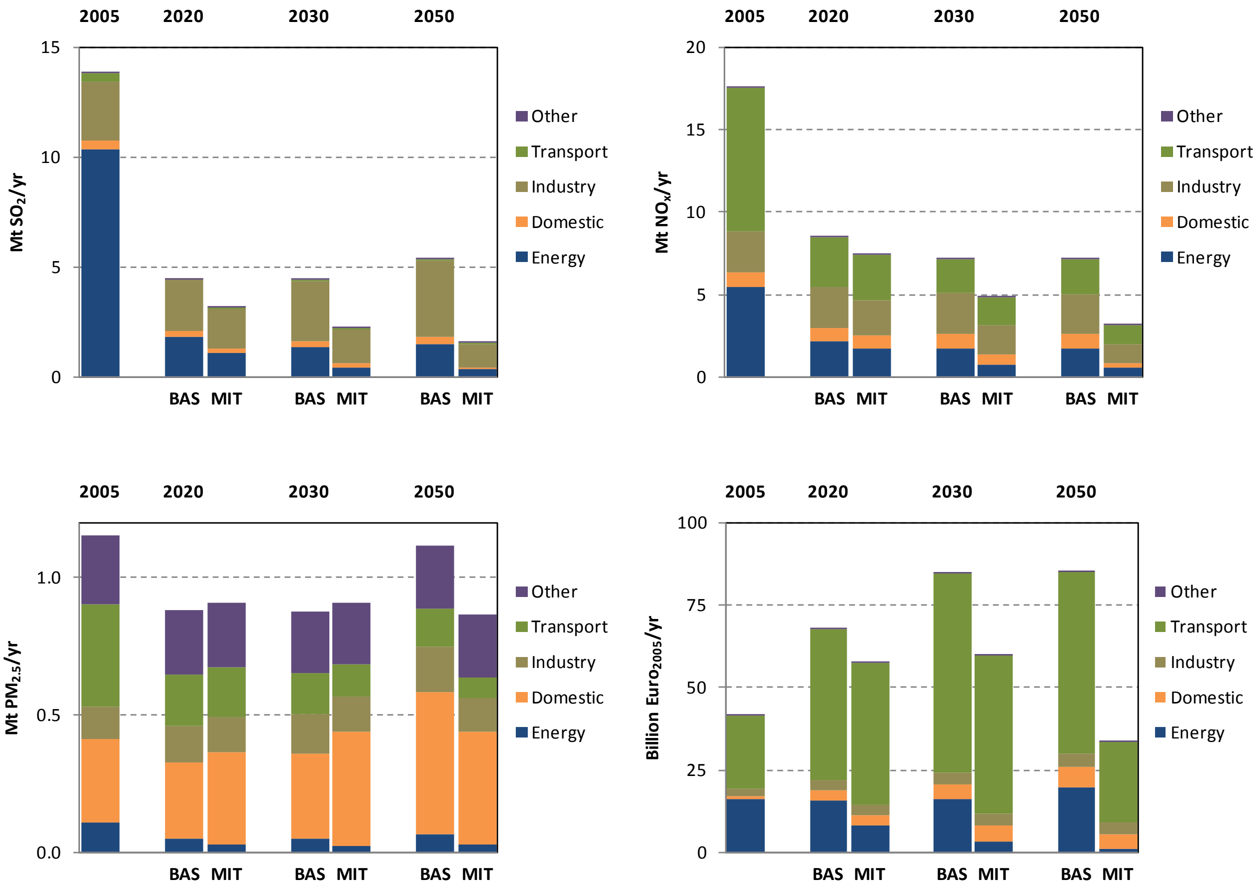


**Figure 13** USA: Emission estimates of $SO_2$ (top left panel), $NO_x$ (top right panel) and $PM_{2.5}$ (low left panel) for the Baseline (BAS) and Mitigation (MIT) scenarios for the period 2005 – 2050; Air pollution control costs by scenarios and by sectors (low right panel).

As also shown in Figure 13, by 2030 the contribution to the cost savings estimated for the Mitigation scenario in the US is equally distributed between the power plants and transport sectors. Until 2050, nearly two thirds of the overall cost reduction is attributed to road and off-road transport. The cost savings from indirect abatement of $SO_2$, $NO_x$ and $PM_{2.5}$, as calculated in GAINS for US in the years 2030 and 2050, are quantified at 25 billion $€_{2005}$/yr and 52 billion $€_{2005}$/yr, respectively, compared to the Baseline scenario.

## 4.3 Comparison of $CO_2$ and air pollutant reductions

The relation between $CO_2$ mitigation and air pollution emissions is further depicted in Figure 14, showing the emissions reductions relative to the year 2005 for both Baseline and Mitigation cases. In the Baseline, $CO_2$ emissions are reduced or stabilised in EU-27 and in US, while fast growing economies of China and India experience a rapid growth in $CO_2$ emissions up to 2050. At the same time, gradual changes in the energy sectors and adoption of emission controls lead to a large decrease in air pollution levels in EU-27 and in US, when compared to present. In China and India, the penetration of abatement technologies keeps the growth in $PM_{2.5}$ emissions at a moderate rate. $SO_2$ emissions are basically stabilised in China by 2050, but the sulphur emissions from Indian installations remain mostly uncontrolled.

In the Mitigation scenario, in large emitting regions with the exception of India, the biggest reduction is achieved for $SO_2$ emissions in 2050, whereas the cuts in $CO_2$ and $SO_2$ emissions are nearly proportional following a massive decrease in the demand for coal for power generation and reduced industrial coal use. An important role in the lowering of $NO_x$ emissions is played by control policies in the road transport sector, however, fuel switches toward natural gas and biomass combustion in the power sector lead to lesser reductions as compared to $SO_2$. Similarly, an increased use of biofuels for combustion in the domestic and industrial sectors limits the $PM_{2.5}$ reduction achieved by the GHG mitigation policies.

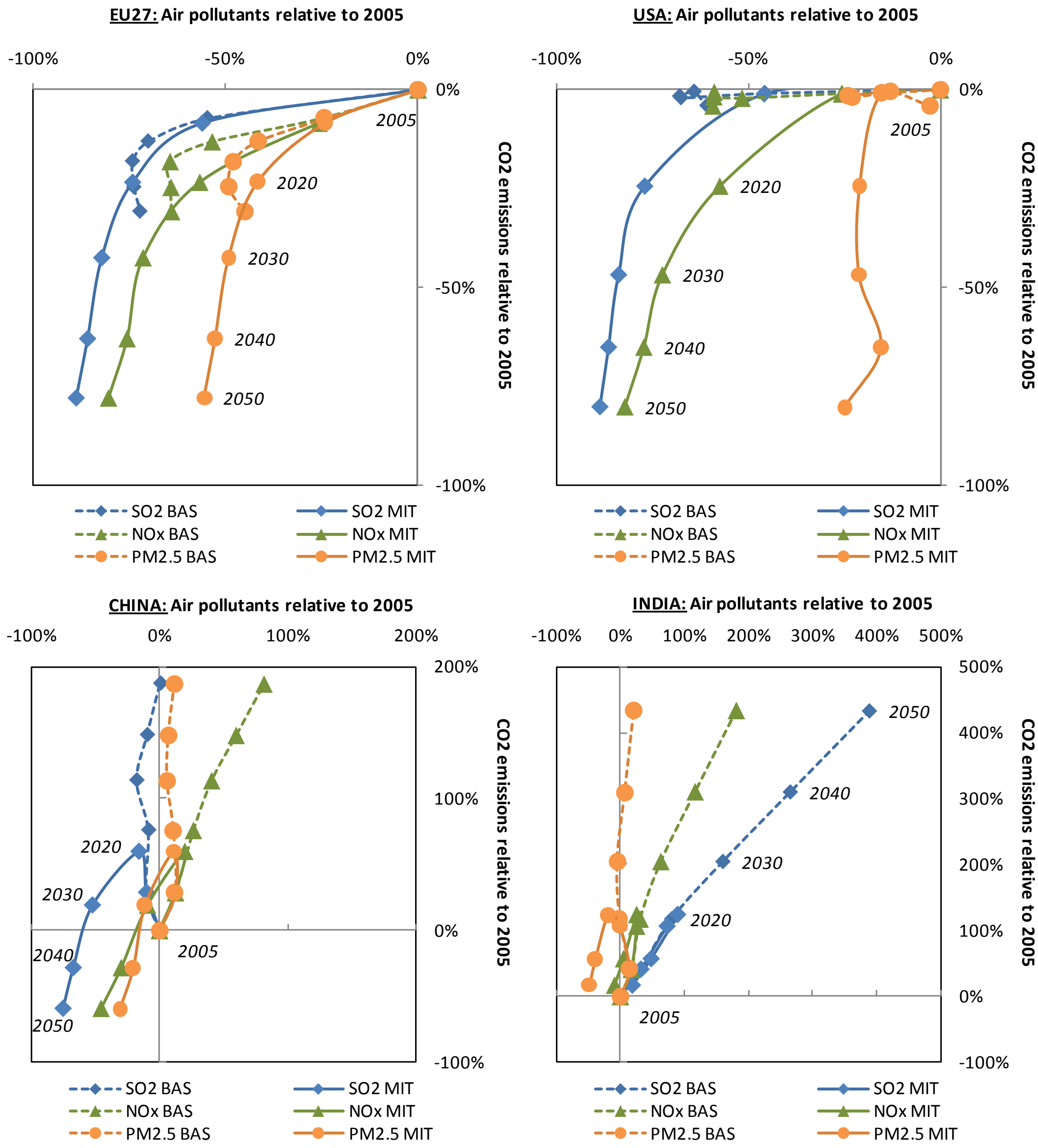


**Figure 14** Reduction of air pollution relative to the $CO_2$ emission reductions in the Baseline and Mitigation scenarios in comparison to the year 2005 in EU-27, US, China and India for the period 2010 – 2050.

## 4.4 Health and environmental impacts

The assessment presented above does not cover the full extent of the potential co-benefits attributable to a climate mitigation strategy. Additional benefits would be expected from reduced health impacts and decreases in crop damage and burdens to ecosystems.

The GAINS model can estimate a range of health and environmental impacts, including the statistical loss of life expectancy attributable to anthropogenic sources of $PM_{2.5}$, premature mortality due to ozone, ecosystems areas with acid deposition or nitrogen deposition exceeding critical loads and crop losses due to ozone. These calculations depend on GAINS emission estimates and the results from detailed atmospheric chemistry and transport models, combined with other necessary data such as critical loads and levels, relative risk factors, population, ecosystems areas, etc. Currently, the GAINS impact assessments are available for Europe, China and India. Countries included cover, however, nearly half of the world population. Ambient $PM_{2.5}$ concentrations include primary $PM_{2.5}$ as well as secondary aerosols (sulphates and nitrates).

Figure 15 illustrates the impact of climate policies on the ambient concentrations of $PM_{2.5}$ up to 2050 for these three regions. High concentrations of $PM_{2.5}$ in the ambient air are directly responsible for severe health damages and declined life expectancy. While in Europe only few countries do not comply with air quality guidelines on $PM_{2.5}$ published by WEO (2005) by 2050, most of regions in China and India are affected by concentrations far above the guideline level of 10 µg $PM_{2.5}$/m3. Weighted by the population in individual sub-regions, average ambient concentrations of $PM_{2.5}$ in EU-27 are by 36% lover in the Mitigation scenario when compared to the Baseline projections in 2050. Corresponding reductions in China and India are quantified at 47% and 63%, respectively.

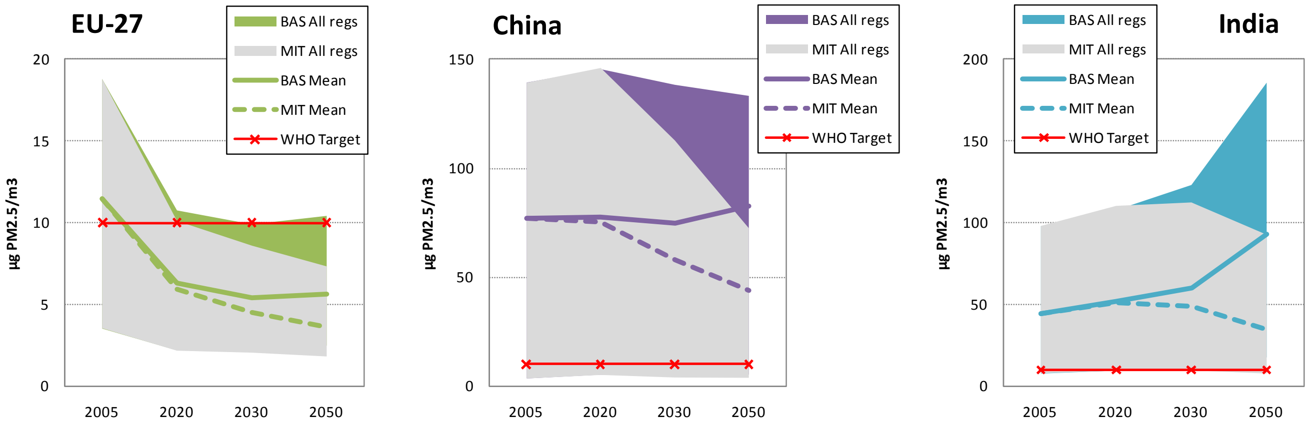


**Figure 15** Ambient concentrations of $PM_{2.5}$ (population weighted, annual mean) for the Baseline and the Mitigation scenarios. Ranges indicate variations over countries/provinces/states.

The following sections provide a selection of health and environmental impact estimates derived from the two POLES scenarios for the three key regions – EU-27, China and India. It is noted that the assessment provided herein considers only outdoor exposure and does not cover negative health effects of indoor air pollution.

### *4.4.1 Europe*

The Baseline case results in more than 50% reduction in the loss in average life expectancy due to $PM_{2.5}$ between 2005 and 2050 in Europe as a whole. The Mitigation scenario achieves a further 35% reduction in 2050 in loss of life expectancy than the Baseline case. Taking a population-weighted average for EU-27 in 2050, loss in statistical life expectancy due to $PM_{2.5}$ for adults older than 30 years attributable to exposure to $PM_{2.5}$ from anthropogenic sources is reduced from 3.4 months in the Baseline to 2.2 months in the Mitigation scenario.

The Mitigation scenario is less effective in reducing premature mortality due to ozone, bringing an improvement of 6% in 2030 and 15% in 2050 relative to the Baseline. In absolute terms, there are nearly 2500 fewer premature deaths attributable to exposure to ground-level ozone in Europe by 2050 in the Mitigation scenario when compared to the Baseline.

Figure 16 shows the spatially distributed impacts of climate policies on loss of life expectancy estimated for European countries, for the Baseline and the Mitigation scenarios in 2050. Distribution of health impacts across European countries is provided in Table A 5 and Table A 6 in Annexes.

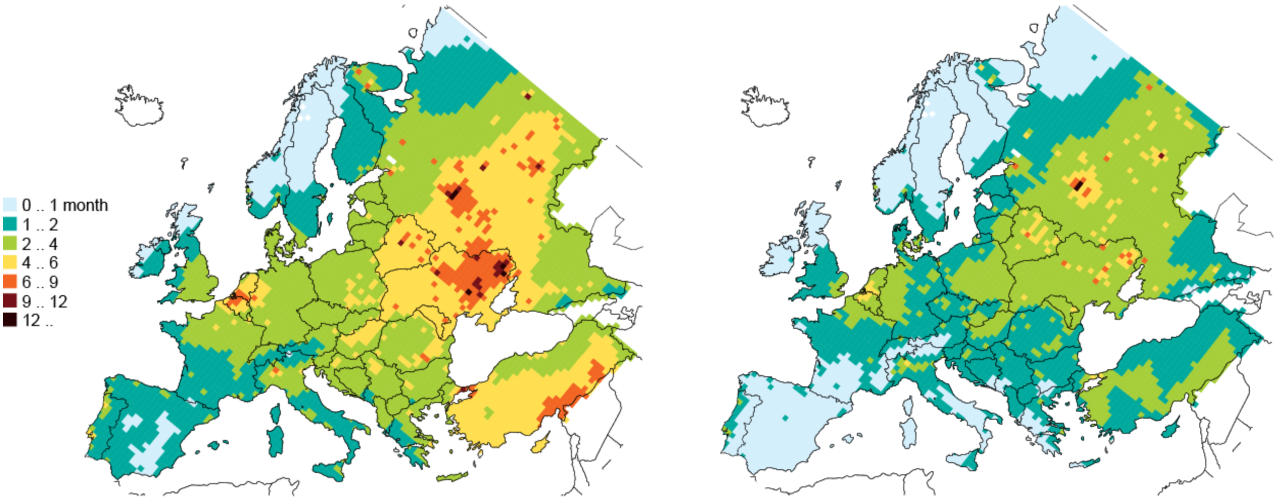


**Figure 16** Statistical loss of life expectancy in Europe due to anthropogenic $PM_{2.5}$ for the Baseline (left panel) and Mitigation (right panel) scenarios in 2050; month.

Impact indicators related to ecosystems in Europe are given in Table A 7 and Table A 8. The Baseline case shows a 70% reduction in the forest area with acid deposition exceeding critical loads between 2005 and 2050. The Mitigation scenario achieves a further 15% reduction in exceeded area than the Baseline case in 2050. As is seen in Figure 17 and Figure 18, the difference between the two scenarios is much less apparent for the area of ecosystems where nitrogen deposition exceeds critical loads in Europe. This is to be expected since the ammonia emissions contributing to the eutrophication are similar in both cases.

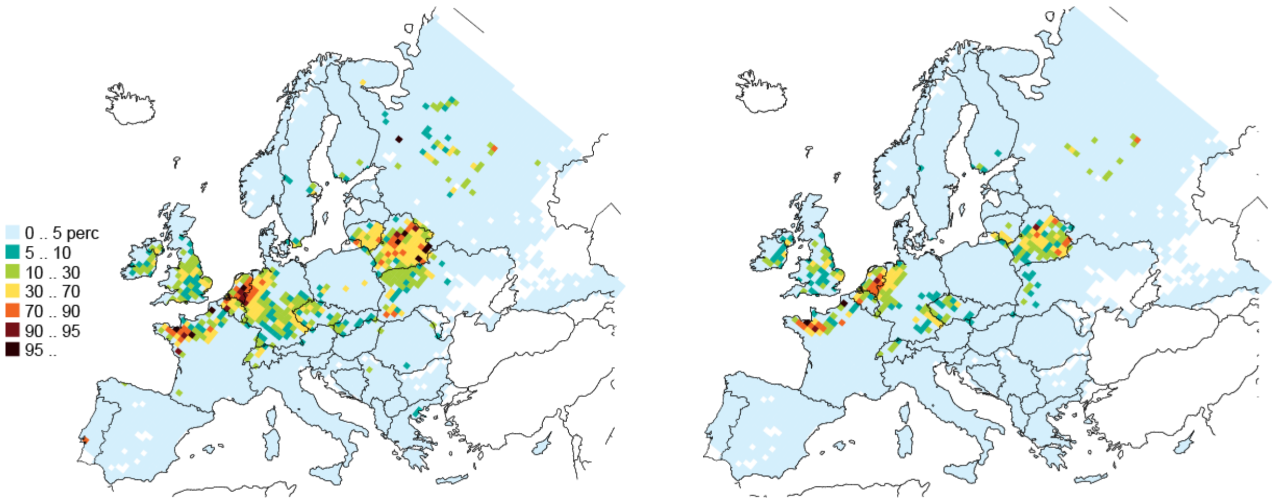


**Figure 17** Exceedance of critical loads for acidification to forest ecosystems in Europe for the Baseline (left panel) and Mitigation (right panel) scenarios in 2050; %.

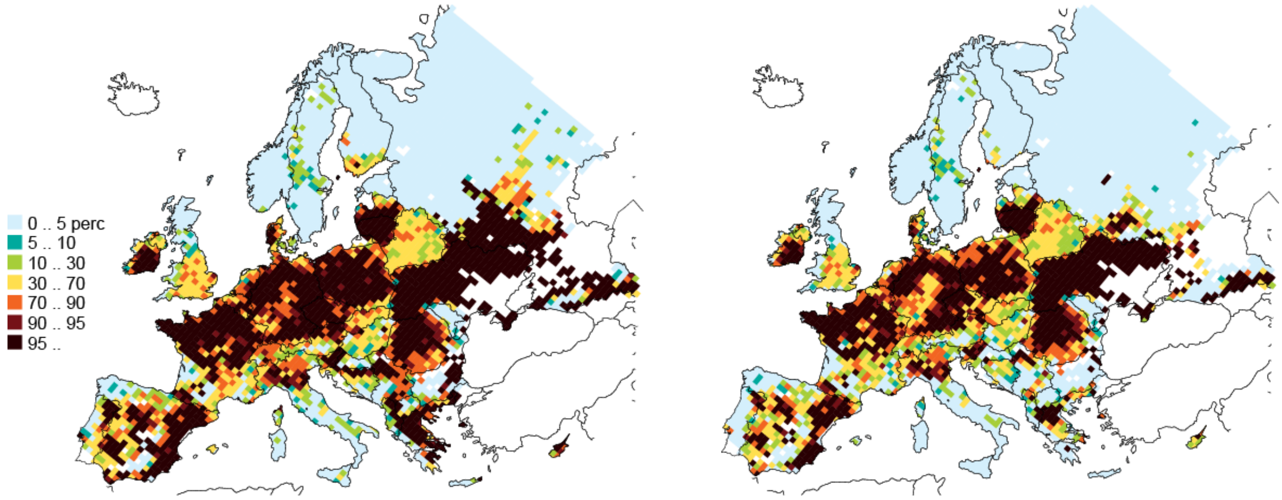


**Figure 18** Exceedance of critical loads for nutrient N to all ecosystems in Europe for the Baseline (left panel) and Mitigation (right panel) scenarios in 2050; %.

### 4.4.2 China

In China, improvements in the health impact indicators brought about by the climate scenario only begin to be seen in 2030, in line with the changes in emissions of air pollutants between the two scenarios. By 2050, loss in statistical life expectancy due to $PM_{2.5}$ is halved in the Mitigation scenario. When compared to the Baseline, the average life expectancy in China increases by nearly 20 months in the end of the computation period. In addition, premature deaths attributable to ozone are reduced annually by 20,000 cases. For individual Chinese provinces, the impact indicators related to human health estimated for the Baseline and the Mitigation scenarios are reported in Table A 5 and Table A 6 in Annexes. Regional distribution of health impacts in the adults population in China attributable to exposure to $PM_{2.5}$ is illustrated in Figure 19.

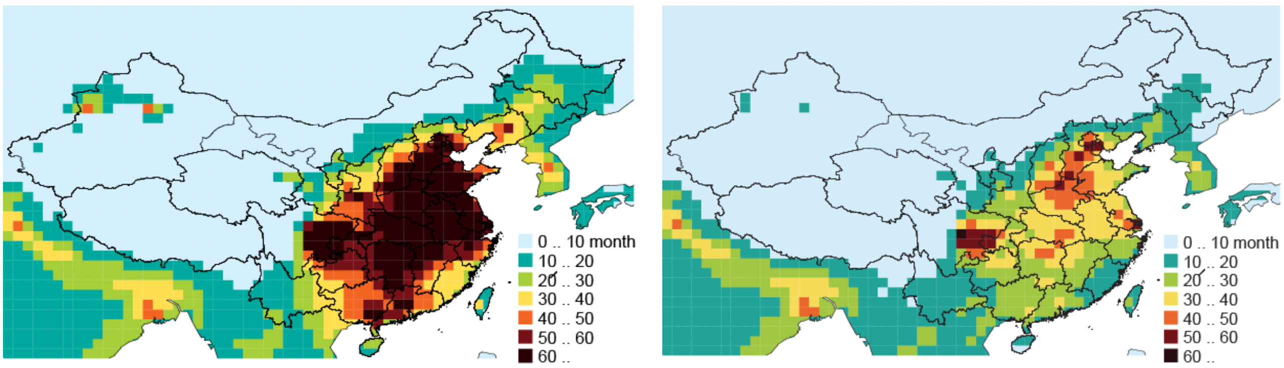


**Figure 19** Statistical loss of life expectancy in China due to anthropogenic $PM_{2.5}$ for the Baseline (left panel) and Mitigation (right panel) scenarios in 2050; month.

### 4.4.3 India

In India too, the climate scenario only really brings improvements in 2030, with 20% reductions in loss of life expectancy and in premature mortality due to ozone. By 2050, the two health indicators are improved significantly showing the annual reductions of above 60% relative to the Baseline. The gain in the statistical life expectancy invoked by the climate policies in India is estimated at 30 months, while the projected premature death-rates due to ground-level ozone are by 55,000 cases annually lower in comparison to the Baseline case. Details on time evolution of the health indicators in Indian states are provided in Table A 5 and Table A 6 in Annexes. Spatial distribution of health impacts because of anthropogenic $PM_{2.5}$ in India is shown in Figure 20.

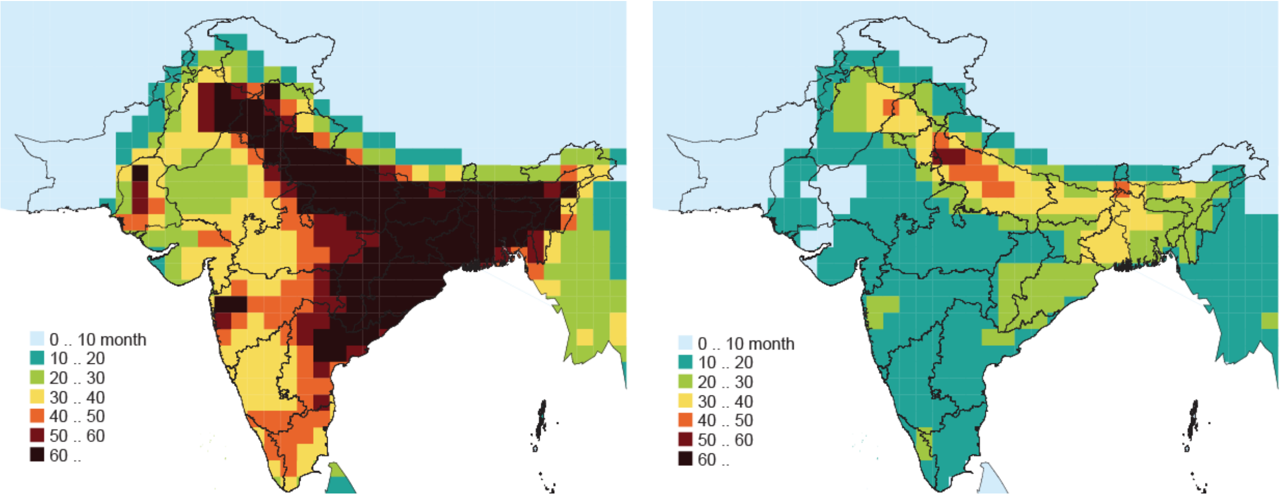


**Figure 20** Statistical loss of life expectancy in India due to anthropogenic $PM_{2.5}$ for the Baseline (left panel) and Mitigation (right panel) scenarios in 2050; month.

# 5 Summary

The European Commission proposed in its Communication to keep the global warming due to GHG emissions to levels not exceeding 2° Celsius. To inform policy makers about the scope of potential co-benefits that might result from stringent climate mitigation strategies by 2050, this report presents a comprehensive analysis of impacts of such policies for air quality and associated effects on human health and ecosystems globally and across the key world regions.

The GAINS model has been used to assess the impact of global greenhouse gas policies on traditional air pollutants ($SO_2$, $NO_x$ and $PM_{2.5}$) world-wide and for regions of EU, China, India and the US. An interface has been established between GAINS and the POLES global energy system model so that the effects of different global energy pathways can be evaluated. The analysis reported herein is based on projections of energy consumption provided by the POLES model for two different scenarios, i.e., for a current policy **Baseline scenario** without any post-2012 global GHG reduction target, and a 2°C climate **Mitigation scenario** which assumes internationally coordinated action to mitigate climate change.

Climate mitigation measures that are assumed in the Mitigation scenario cause significant changes in national energy systems. At the same time, current legislation implemented or foreseen across countries aims at substantial improvements in air quality. In this context the potential co-benefits result solely as a secondary benefit of the enforced reconfiguration of the energy system. In other words, the same air pollution control policies are taken into account in both scenarios under examination. The calculations presented in this report assume a successful adoption of current legislation in the time horizon up to 2030 and no strengthening of the legislation between 2030 and 2050.

The projections of $SO_2$, $NO_x$ and $PM_{2.5}$ emissions in the Mitigation scenario reveal important reductions in all three pollutants by 2050 and correspond globally to relative decrease over the Baseline of 70%, 60% and 30%, respectively. The scope of emission reduction in different regions depends on the fuel and technology shifts under GHGs constraints, as well as being determined by the rate of adoption of the air quality policies. Because of these factors, the potential for co-benefits is estimated to be higher in fast growing economies of China and India as compared to industrialised regions of EU-27 and US. On the other hand, trade-offs have been shown in the periods 2020 and 2030 resulting in the higher $PM_{2.5}$ and $NO_x$ emissions in the Mitigation scenario due to an increase in biomass consumption, particularly in the domestic sector.

Quantification of control costs incurred by the adoption of current air pollution legislation indicates the scale of the savings that are made possible through global climate policies. Expenditures on air pollution control in the Mitigation scenario are reduced in 2050 by 250 billion €/year compared with the Baseline case. The corresponding annual reductions in EU-27, China and India are estimated at 35, 83, 8 and 52 billion $€_{2005}$, respectively. In general, the largest cost saving potential has been found in the road transport sector, followed by the power generation sector. Relative contribution of these sectors to overall cost savings is 60% for transport and 30% for the power sector.

The analysis shows further that there is a substantial share of population exposed to ambient concentrations of $PM_{2.5}$, which are significantly higher than levels recommended by the WHO guidelines. Although the concentrations of particulates in regions of China and India drop rapidly under climate policies when compared to the Baseline emission levels, these policies are not effective enough to bring the $PM_{2.5}$ exposures to the desired standards. This indicates that the current policy set-up will have to be extended and further targeted abatement measures need to be taken in order to offset the growth in emissions associated with the fossil fuels combustion.

Our results demonstrate that impact of air pollution on human health is much lower for the scenario with stringent climate measures. In 2050, loss of life expectancy in Europe, China and India attributable to the exposure from anthropogenic emissions of $PM_{2.5}$ decreases in the Mitigation scenario by 35%, 46% and 63%, respectively. When expressed in absolute terms, the average life expectancy in 2050 increases by 1.2 months in Europe, 19 months in China and nearly 30 months in India. Furthermore, the climate policies reduce premature mortality due to ground level ozone by 80 thousand cases yearly in these three regions combined.

The co-benefits of the air pollution control and climate strategies for ecosystems have been calculated for Europe and comprise impacts on acidification and eutrophication. The forest area exposed to acidification deposition exceeding critical loads in 2050 is by 42 thousand $km^2$ less in the Mitigation scenario as compared to the Baseline. Co-benefits for ecosystems area with nitrogen deposition in excess of the critical loads for eutrophication in EU-27 is less pronounced in the Mitigation scenario because of the growing ammonia emissions from agriculture, nevertheless the affected area in 2050 is smaller by 145 thousand $km^2$ due to less $NO_x$ from fuel combustion.

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# Appendix I - Mapping of POLES and GAINS regions

| POLES | GAINS regions |
|---|---|
| BRA | BRAZ_WHOL |
| CAN | CANA_WHOL |
| CHN | CHIN_* (all Chinese regions in GAINS) |
| COR | KORS_NORT KORS_PUSA KORS_SEOI KORS_SOUT |
| EGY | EGYP_WHOL |
| EU-27 | AUST_WHOL BELG_WHOL BULG_WHOL CYPR_WHOL CZRE_WHOL DENM_WHOL ESTO_WHOL FINL_WHOL FRAN_WHOL GERM_WHOL GREE_WHOL HUNG_WHOL IREL_WHOL ITAL_WHOL LATV_WHOL LITH_WHOL LUXE_WHOL MALT_WHOL NETH_WHOL POLA_WHOL PORT_WHOL ROMA_WHOL SKRE_WHOL SLOV_WHOL SPAI_WHOL SWED_WHOL UNKI_WHOL |
| JPN | JAPA_CHSH JAPA_CHUB JAPA_HOTO JAPA_KANT JAPA_KINK JAPA_KYOK |
| MEME | MIDE_WHOL |
| MEX | MEXI_WHOL |
| NDE | INDI_* (all Indian regions in GAINS) |
| NOAN | NAFR_WHOL |
| RCEU | ALBA_WHOL BOHE_WHOL CROA_WHOL MACE_WHOL SEMO_WHOL |
| RIS | ARME_WHOL AZER_WHOL BELA_WHOL FSUA_WHOL GEOR_WHOL KAZA_WHOL KYRG_WHOL MOLD_WHOL |
| RJAN | AUTR_WHOL NZEL_WHOL |
| ROWE | ICEL_WHOL NORW_WHOL SWIT_WHOL |
| RSAM | ARGE_WHOL CHIL_WHOL OLAM_WHOL |
| RSAS | AFGH_WHOL BANG_DHAK BANG_REST BHUT_WHOL NEPA_WHOL PAKI_KARA PAKI_NMWP PAKI_PUNJ PAKI_SIND SRIL_WHOL |
| RSEA | BRUN_WHOL CAMB_WHOL INDO_JAKA INDO_JAVA INDO_REST INDO_SUMA KORN_WHOL LAOS_WHOL MALA_KUAL MALA_PENM MALA_SASA MONG_WHOL MYAN_WHOL PHIL_BVMI PHIL_LUZO PHIL_MANI SING_WHOL TAIW_WHOL THAI_BANG THAI_CVAL THAI_NEPL THAI_NHIG THAI_SPEN VIET_NORT VIET_SOUT |
| RUS | RUSS_ASIA RUSS_EURO |
| SSAF | OAFR_WHOL SAFR_WHOL |
| TUR | TURK_WHOL |
| UKR | UKRA_WHOL |
| USA | USAM_WHOL |

## Appendix II - Mapping of POLES and GAINS sectors and activities

| POLES sector | POLES activity | | GAINS activity | GAINS sector |
|---|---|---|---|---|
| Agriculture(AGR) | BIO | | CHCOA FWD | DOM_OTH |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | DOM_OTH |
| | GAS | | GAS | DOM_OTH TRA_OT_AGR |
| | OIL | | GSL HF LPG MD | DOM_OTH |
| | | | GSL LPG MD | TRA_OT_AGR |
| Air(ART) | OIL | | GSL | TRA_OT_AIR |
| Biomass(BIOINEL) | BIO | | FWD | PP_EX_OTH PP_IGCC PP_NEW |
| BIOINEL_CAPTURE | BIO | | FWD | PP_IGCC_CCS PP_NEW_CCS |
| CAR | VNRCAR | | GAS_NV GSL_NV LPG_NV MD_NV | TRA_RD_LD4C TRA_RD_LD4T |
| Feedstocks(CHF) | BIO | | WSFR | NONEN |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | NONEN |
| | GAS | | GAS | NONEN |
| | OIL | | GSL HF LPG MD | NONEN |
| Chemical(CHI) | BIO | | FWD | IN_CHEM_BO IN_CHEM_OC |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | IN_CHEM_BO IN_CHEM_OC |
| | GAS | | GAS | IN_CHEM_BO IN_CHEM_OC |
| | OIL | | GSL HF LPG MD | IN_CHEM_BO IN_CHEM_OC |
| Gas(GAFINEL) | GAS | | GAS | PP_EX_OTH PP_NEW |
| GAFINEL_CAPTURE | GAS | | GAS | PP_NEW_CCS |
| GDP | GDP_PPP | | GDP_PPP | MACRO |
| HEV | BIO | | GSL GSL_M MD MD_M | TRA_RD_HDB TRA_RD_HDT |
| | OIL | | GSL_M LPG MD_M | TRA_RD_HDB TRA_RD_HDT |
| IND | VA_IND | | VA_IND | MACRO |
| Liquids(LIFINEL) | OIL | | GSL HF MD | PP_EX_OTH PP_NEW |
| | | | HF | PP_IGCC |
| LIFINEL_CAPTURE | OIL | | HF | PP_IGCC_CCS |

| POLES sector | POLES activity | | GAINS activity | GAINS sector |
|---|---|---|---|---|
| | | | HF MD | PP_NEW_CCS |
| Lignite(LIGINEL) | BC | | BC1 BC2 | PP_EX_OTH PP_IGCC PP_NEW |
| LIGINEL_CAPTURE | BC | | BC1 BC2 | PP_IGCC_CCS PP_NEW_CCS |
| LIV | VKMLIV | | GAS_KM GSL_KM H2_KM LPG_KM MD_KM | TRA_RD_LD4C TRA_RD_LD4T |
| Non-metallic Minerals (NMM) | BIO | | FWD | IN_NMMI_OC |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | IN_NMMI_OC |
| | GAS | | GAS | IN_NMMI_OC |
| | OIL | | GSL HF LPG MD | IN_NMMI_OC |
| Other Industry(OIN) | BIO | | FWD | IN_NFME_OC IN_OTH_BO IN_OTH_OC IN_PAP_BO IN_PAP_OC |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | IN_NFME_OC IN_OTH_BO IN_OTH_OC IN_PAP_BO IN_PAP_OC |
| | GAS | | GAS | IN_NFME_OC IN_OTH_BO IN_OTH_OC IN_PAP_BO IN_PAP_OC TRA_OT_CNS |
| | OIL | | GSL HF LPG MD | IN_NFME_OC IN_OTH_BO IN_OTH_OC IN_PAP_BO IN_PAP_OC |
| | | | GSL LPG MD | TRA_OT_CNS |
| Non-road other (OTT) | BIO | | GSL GSL_M | TRA_OT_LD2 |
| | | | GSL GSL_M MD MD_M | TRA_OT_CNS TRA_OT_INW TRA_OT_LB |
| | | | MD MD_M | TRA_OTS_L TRA_OTS_M |
| | GAS | | GAS | TRA_OT_INW TRA_OT_LB TRA_OT_LD2 TRA_OTS_L TRA_OTS_M |
| | OIL | | GSL GSL_M MD MD_M | TRA_OT_CNS |
| | | | GSL_M | TRA_OT_LD2 |
| | | | GSL_M LPG MD_M | TRA_OT_LB |
| | | | GSL_M MD_M | TRA_OT_INW |
| | | | HF MD_M | TRA_OTS_L |
| | | | MD_M | TRA_OTS_M |
| PEOIL | OIL | | NOF | PR_REF |
| POP | POP_ANY | | POP | ANY |

| POLES sector | POLES activity | | GAINS activity | GAINS sector |
|---|---|---|---|---|
| Rail(RAT) | BIO | | GSL GSL_M MD MD_M | TRA_OT_RAI |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | TRA_OT |
| | GAS | | GAS | TRA_OT_RAI |
| | OIL | | GSL_M MD_M | TRA_OT_RAI |
| Residential(RES) | BIO | | CHCOA FWD | DOM_RES |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | DOM_RES |
| | GAS | | GAS | DOM_RES |
| | OIL | | GSL HF LPG MD | DOM_RES |
| Road (ROT) | BIO | | GSL GSL_M | TRA_RD_LD2 TRA_RD_M4 |
| | | | GSL GSL_M MD MD_M | TRA_OT_AGR TRA_RD_LD4C TRA_RD_LD4T |
| | GAS | | GAS | TRA_RD_HDB TRA_RD_HDT TRA_RD_LD2 TRA_RD_LD4C TRA_RD_LD4T TRA_RD_M4 |
| | OIL | | GSL GSL_M MD MD_M | TRA_OT_AGR |
| | | | GSL_M LPG | TRA_RD_LD2 TRA_RD_M4 |
| | | | GSL_M LPG MD_M | TRA_RD_LD4C TRA_RD_LD4T |
| Services (SER) | BIO | | CHCOA FWD | DOM_COM |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | DOM_COM |
| | GAS | | GAS | DOM_COM |
| | OIL | | GSL HF LPG MD | DOM_COM |
| | VA_SER | | VA_TERT | MACRO |
| Solids (SOFINEL) | COAL | | BC1 BC2 DC HC1 HC2 HC3 | PP_EX_OTH PP_IGCC PP_NEW |
| | | | HC1 HC2 HC3 | PP_EX_WB |
| SOFINEL_CAPTURE | COAL | | BC1 BC2 HC1 HC2 HC3 | PP_IGCC_CCS PP_NEW_CCS |
| Iron & Steel (STI) | BIO | | FWD | IN_ISTE_OC |
| | COAL | | BC1 BC2 DC HC1 HC2 HC3 | IN_ISTE_OC |
| Iron & Steel (STI) | GAS | | GAS | IN_ISTE_OC |

| **POLES sector** | **POLES activity** | | **GAINS activity** | **GAINS sector** |
|---|---|---|---|---|
| | OIL | | GSL HF LPG MD | IN_ISTE_OC |
| | TONSTI | | NOF | PR_BAOX PR_CAST PR_CAST_F PR_COKE PR_EARC PR_HEARTH PR_PELL PR_PIGI PR_PIGI_F PR_SINT PR_SINT_F STH_FEORE |

# Appendix III - World regions covered by GAINS

| GAINS Abbreviation | Country | Region(s) |
|---|---|---|
| AFGH_WHOL | Afghanistan | |
| ALBA_WHOL | Albania | |
| ARGE_WHOL | Argentina | |
| ARME_WHOL | Armenia | |
| AUST_WHOL | Austria | |
| AUTR_WHOL | Australia | |
| AZER_WHOL | Azerbaijan | |
| BANG_DHAK | Bangladesh | Dhaka |
| BANG_REST | Bangladesh | Rest of Bangladesh |
| BELA_WHOL | Belarus | |
| BELG_WHOL | Belgium | |
| BHUT_WHOL | Bhutan | |
| BOHE_WHOL | Bosnia and Herzegovina | |
| BRAZ_WHOL | Brazil | |
| BRUN_WHOL | Brunei | |
| BULG_WHOL | Bulgaria | |
| CAMB_WHOL | Cambodia | |
| CANA_WHOL | Canada | |
| CHIL_WHOL | Chile | |
| CHIN_ANHU | China | Anhui |
| CHIN_BEIJ | China | Beijing |
| CHIN_CHON | China | Chongqing |
| CHIN_FUJI | China | Fujian |
| CHIN_GANS | China | Gansu |
| CHIN_GUAD | China | Guangdong |
| CHIN_GUAX | China | Guangxi |
| CHIN_GUIZ | China | Guizhou |
| CHIN_HAIN | China | Hainan |
| CHIN_HEBE | China | Hebei |
| CHIN_HEIL | China | Heilongjiang |
| CHIN_HENA | China | Henan |
| CHIN_HONG | China | Hong Kong & Macau |
| CHIN_HUBE | China | Hubei |
| CHIN_HUNA | China | Hunan |
| CHIN_JILI | China | Jilin |
| CHIN_JINU | China | Jiangsu |
| CHIN_JINX | China | Jiangxi |
| CHIN_LIAO | China | Liaoning |
| CHIN_NEMO | China | Inner Mongolia |
| CHIN_NINX | China | Ningxia |

| GAINS Abbreviation | Country | Region(s) |
|---|---|---|
| CHIN_QING | China | Qinghai |
| CHIN_SHAA | China | Shaanxi |
| CHIN_SHAN | China | Shanghai |
| CHIN_SHND | China | Shandong |
| CHIN_SHNX | China | Shanxi |
| CHIN_SICH | China | Sichuan |
| CHIN_TIAN | China | Tianjin |
| CHIN_TIBE | China | Tibet (Xizang) |
| CHIN_XING | China | Xinjiang |
| CHIN_YUNN | China | Yunnan |
| CHIN_ZHEJ | China | Zhejiang |
| CROA_WHOL | Croatia | |
| CYPR_WHOL | Cyprus | |
| CZRE_WHOL | Czech Republic | |
| DENM_WHOL | Denmark | |
| EGYP_WHOL | Egypt | |
| ESTO_WHOL | Estonia | |
| FINL_WHOL | Finland | |
| FRAN_WHOL | France | |
| FSUA_WHOL | Other Former USSR, Asia | |
| GEOR_WHOL | Georgia | |
| GERM_WHOL | Germany | |
| GREE_WHOL | Greece | |
| HUNG_WHOL | Hungary | |
| ICEL_WHOL | Iceland | |
| INDI_ANPR | India | Andhra Pradesh |
| INDI_ASSA | India | Assam |
| INDI_BENG | India | West Bengal |
| INDI_BIHA | India | Bihar |
| INDI_CHHA | India | Chhattisgarh |
| INDI_DELH | India | Delhi |
| INDI_EHIM | India | North East (excl. Assam) |
| INDI_GOA | India | Goa |
| INDI_GUJA | India | Gujarat |
| INDI_HARY | India | Haryana |
| INDI_HIPR | India | Himachal Pradesh |
| INDI_JHAR | India | Jharkhand |
| INDI_KARN | India | Karnataka |
| INDI_KERA | India | Kerala |
| INDI_MAHA | India | Maharashtra-Dadra-Nagar Haveli-Daman-Diu |
| INDI_MAPR | India | Madhya Pradesh |
| INDI_ORIS | India | Orissa |

| GAINS Abbreviation | Country | Region(s) |
|---|---|---|
| INDI_PUNJ | India | Punjab (India) |
| INDI_RAJA | India | Rajasthan |
| INDI_TAMI | India | Tamil Nadu |
| INDI_UTAN | India | Uttaranchal |
| INDI_UTPR | India | Uttar Pradesh |
| INDI_WHIM | India | Jammu and Kashmir |
| INDO_JAKA | Indonesia | Jakarta |
| INDO_JAVA | Indonesia | Java |
| INDO_REST | Indonesia | Rest of Indonesia |
| INDO_SUMA | Indonesia | Sumatra |
| IREL_WHOL | Ireland | |
| ISRA_WHOL | Israel | |
| ITAL_WHOL | Italy | |
| JAPA_CHSH | Japan | Chugoku-Shikoku |
| JAPA_CHUB | Japan | Chubu |
| JAPA_HOTO | Japan | Hokkaido-Tohoku |
| JAPA_KANT | Japan | Kanto |
| JAPA_KINK | Japan | Kinki |
| JAPA_KYOK | Japan | Kyushu-Okinawa |
| KAZA_WHOL | Kazakhstan | |
| KORN_WHOL | Korea (North) | |
| KORS_NORT | South Korea | North |
| KORS_PUSA | South Korea | Pusan |
| KORS_SEOI | South Korea | Seoul-Inchon |
| KORS_SOUT | South Korea | South |
| KYRG_WHOL | Kyrgyzstan | |
| LAME_WHOL | Latin America | |
| LAOS_WHOL | Laos | |
| LATV_WHOL | Latvia | |
| LITH_WHOL | Lithuania | |
| LUXE_WHOL | Luxembourg | |
| MACE_WHOL | Macedonia | |
| MALA_KUAL | Malaysia | Kuala Lumpur |
| MALA_PENM | Malaysia | Peninsular Malaysia |
| MALA_SASA | Malaysia | Sarawak-Sabah |
| MALT_WHOL | Malta | |
| MEXI_WHOL | Mexico | |
| MIDE_WHOL | Middle East | |
| MOLD_WHOL | Republic of Moldova | |
| MONG_WHOL | Mongolia | |
| MYAN_WHOL | Myanmar | |
| NAFR_WHOL | North Africa | Libya, Tunisia, Algeria, Sudan, Morocco |

| GAINS Abbreviation | Country | Region(s) |
|---|---|---|
| NEPA_WHOL | Nepal | |
| NETH_WHOL | Netherlands | |
| NORW_WHOL | Norway | |
| NZEL_WHOL | New Zealand | |
| OAFR_WHOL | Other Africa | |
| OLAM_WHOL | Other Latin America | |
| PAKI_KARA | Pakistan | Karachi |
| PAKI_NMWP | Pakistan | NW Frontier Provinces-Baluchistan |
| PAKI_PUNJ | Pakistan | Punjab (Pakistan) |
| PAKI_SIND | Pakistan | Sind |
| PHIL_BVMI | Phillipines | Bicol-Visayas-Mindanao |
| PHIL_LUZO | Phillipines | Luzon |
| PHIL_MANI | Phillipines | Metro Manila |
| POLA_WHOL | Poland | |
| PORT_WHOL | Portugal | |
| ROMA_WHOL | Romania | |
| RUSS_ASIA | Russia | Russia Asian part |
| RUSS_EURO | Russia | Russia European part |
| SAFR_WHOL | Republic of South Africa | |
| SEMO_WHOL | Serbia and Montenegro | |
| SING_WHOL | Singapore | |
| SKRE_WHOL | Slovak Republic | |
| SLOV_WHOL | Slovenia | |
| SPAI_WHOL | Spain | |
| SRIL_WHOL | Sri Lanka | |
| SWED_WHOL | Sweden | |
| SWIT_WHOL | Switzerland | |
| TAIW_WHOL | Taiwan | |
| THAI_BANG | Thailand | Bangkok Metropolitan Region |
| THAI_CVAL | Thailand | Central Valley |
| THAI_NEPL | Thailand | NE Plateau |
| THAI_NHIG | Thailand | N Highlands |
| THAI_SPEN | Thailand | S Peninsula |
| TURK_WHOL | Turkey | |
| UKRA_WHOL | Ukraine | |
| UNKI_WHOL | United Kingdom | |
| USAM_WHOL | United States of America | |
| VIET_NORT | Vietnam | North: Red River Delta-Hanoi |
| VIET_SOUT | Vietnam | South: Mekong River Delta-Ho Chi Minh City |

# APPENDIX IV – Air pollutant emissions

**Table A 1** Air pollutant emissions in Europe by countries, for the Baseline and the Mitigation scenarios (Mt/year)

| SO2 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Country*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Austria | 27 | 19 | 17 | 22 | 17 | 12 | 12 |
| Belgium | 139 | 102 | 114 | 134 | 84 | 74 | 57 |
| Bulgaria | 901 | 54 | 61 | 68 | 42 | 36 | 24 |
| Cyprus | 39 | 3 | 4 | 4 | 3 | 3 | 2 |
| Czech Rep. | 198 | 92 | 50 | 49 | 82 | 36 | 17 |
| Denmark | 17 | 12 | 9 | 21 | 11 | 8 | 13 |
| Estonia | 77 | 15 | 10 | 13 | 11 | 5 | 3 |
| Finland | 69 | 27 | 28 | 40 | 22 | 18 | 15 |
| France | 484 | 194 | 171 | 190 | 168 | 126 | 87 |
| Germany | 510 | 303 | 249 | 229 | 265 | 180 | 94 |
| Greece | 540 | 106 | 82 | 81 | 97 | 65 | 31 |
| Hungary | 128 | 58 | 49 | 67 | 50 | 31 | 22 |
| Ireland | 77 | 27 | 24 | 23 | 24 | 17 | 9 |
| Italy | 350 | 160 | 145 | 152 | 141 | 111 | 85 |
| Latvia | 5 | 6 | 5 | 6 | 5 | 3 | 2 |
| Lithuania | 46 | 15 | 15 | 15 | 13 | 10 | 6 |
| Luxembourg | 2 | 3 | 3 | 3 | 4 | 4 | 4 |
| Malta | 12 | 0 | 0 | 0 | 1 | 0 | 0 |
| Netherlands | 60 | 38 | 33 | 30 | 35 | 26 | 15 |
| Poland | 1236 | 424 | 260 | 174 | 397 | 179 | 71 |
| Portugal | 224 | 62 | 59 | 55 | 49 | 42 | 27 |
| Romania | 822 | 142 | 140 | 188 | 95 | 73 | 50 |
| Slovakia | 90 | 26 | 25 | 30 | 24 | 21 | 14 |
| Slovenia | 40 | 16 | 11 | 10 | 14 | 8 | 5 |
| Spain | 1234 | 302 | 360 | 424 | 260 | 237 | 151 |
| Sweden | 35 | 26 | 24 | 36 | 24 | 20 | 22 |
| UK | 691 | 178 | 134 | 173 | 148 | 96 | 69 |
| **EU27** | **8053** | **2411** | **2083** | **2239** | **2086** | **1440** | **906** |

| NOx | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Country*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Austria | 201 | 91 | 66 | 81 | 84 | 53 | 43 |
| Belgium | 291 | 173 | 159 | 186 | 152 | 114 | 89 |
| Bulgaria | 183 | 62 | 49 | 46 | 58 | 40 | 25 |
| Cyprus | 20 | 8 | 6 | 7 | 7 | 5 | 3 |
| Czech Rep. | 289 | 144 | 107 | 95 | 131 | 85 | 45 |
| Denmark | 188 | 79 | 57 | 97 | 73 | 47 | 59 |
| Estonia | 36 | 19 | 13 | 14 | 16 | 7 | 4 |
| Finland | 209 | 119 | 73 | 91 | 105 | 54 | 53 |
| France | 1275 | 589 | 443 | 482 | 541 | 349 | 241 |
| Germany | 1413 | 657 | 522 | 525 | 605 | 410 | 270 |
| Greece | 331 | 205 | 163 | 120 | 223 | 155 | 73 |
| Hungary | 165 | 102 | 91 | 87 | 95 | 71 | 41 |
| Ireland | 130 | 73 | 53 | 51 | 67 | 43 | 26 |
| Italy | 1259 | 544 | 399 | 375 | 514 | 333 | 224 |
| Latvia | 38 | 22 | 13 | 13 | 21 | 10 | 7 |
| Lithuania | 65 | 33 | 29 | 28 | 30 | 22 | 14 |
| Luxembourg | 49 | 22 | 14 | 14 | 24 | 17 | 13 |
| Malta | 10 | 2 | 1 | 2 | 2 | 1 | 1 |
| Netherlands | 386 | 189 | 157 | 153 | 178 | 130 | 91 |
| Poland | 792 | 393 | 259 | 243 | 366 | 208 | 143 |
| Portugal | 246 | 108 | 85 | 87 | 96 | 63 | 46 |
| Romania | 300 | 121 | 93 | 107 | 106 | 66 | 50 |
| Slovakia | 97 | 45 | 37 | 37 | 42 | 29 | 20 |
| Slovenia | 53 | 27 | 17 | 15 | 25 | 13 | 8 |
| Spain | 1484 | 691 | 507 | 512 | 640 | 407 | 280 |
| Sweden | 202 | 82 | 58 | 86 | 76 | 47 | 49 |
| UK | 1511 | 620 | 517 | 480 | 576 | 420 | 274 |
| **EU27** | **11221** | **5219** | **3991** | **4034** | **4854** | **3200** | **2190** |

| PM2.5 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Country*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Austria | 22 | 10 | 8 | 14 | 10 | 8 | 11 |
| Belgium | 28 | 19 | 20 | 22 | 18 | 20 | 21 |
| Bulgaria | 50 | 26 | 22 | 20 | 25 | 20 | 15 |
| Cyprus | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| Czech Rep. | 33 | 21 | 16 | 14 | 21 | 16 | 10 |
| Denmark | 31 | 16 | 13 | 55 | 16 | 13 | 37 |
| Estonia | 19 | 7 | 6 | 5 | 7 | 5 | 3 |
| Finland | 26 | 16 | 15 | 14 | 16 | 14 | 11 |
| France | 315 | 187 | 154 | 133 | 190 | 160 | 128 |
| Germany | 123 | 65 | 73 | 72 | 64 | 69 | 52 |
| Greece | 56 | 28 | 27 | 29 | 27 | 27 | 25 |
| Hungary | 27 | 19 | 17 | 21 | 20 | 17 | 16 |
| Ireland | 13 | 6 | 6 | 5 | 6 | 5 | 4 |
| Italy | 121 | 65 | 66 | 88 | 66 | 64 | 72 |
| Latvia | 18 | 13 | 10 | 8 | 13 | 9 | 6 |
| Lithuania | 13 | 10 | 8 | 8 | 9 | 7 | 6 |
| Luxembourg | 3 | 2 | 3 | 4 | 2 | 3 | 5 |
| Malta | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Netherlands | 26 | 27 | 25 | 25 | 27 | 24 | 22 |
| Poland | 132 | 88 | 66 | 63 | 94 | 71 | 55 |
| Portugal | 103 | 70 | 69 | 71 | 67 | 60 | 49 |
| Romania | 152 | 97 | 80 | 69 | 97 | 79 | 58 |
| Slovakia | 19 | 7 | 7 | 8 | 7 | 8 | 7 |
| Slovenia | 9 | 5 | 4 | 3 | 5 | 3 | 2 |
| Spain | 136 | 72 | 68 | 69 | 70 | 61 | 51 |
| Sweden | 29 | 16 | 15 | 16 | 16 | 15 | 14 |
| UK | 86 | 38 | 33 | 38 | 38 | 32 | 31 |
| **EU27** | **1595** | **931** | **831** | **877** | **932** | **813** | **710** |

**Table A 2** Air pollutant emissions in China by provinces, for the Baseline and the Mitigation scenarios (Mt/year)

| SO2 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Province*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Anhui | 790 | 770 | 701 | 800 | 694 | 416 | 227 |
| Beijing | 550 | 755 | 844 | 774 | 1020 | 897 | 287 |
| Chongqing | 572 | 656 | 629 | 619 | 542 | 311 | 144 |
| Fujian | 524 | 434 | 354 | 481 | 403 | 198 | 122 |
| Gansu | 340 | 294 | 246 | 298 | 274 | 167 | 117 |
| Guangdong | 1949 | 1407 | 1188 | 1619 | 1314 | 673 | 377 |
| Guangxi | 759 | 697 | 635 | 821 | 637 | 352 | 183 |
| Guizhou | 512 | 598 | 539 | 602 | 531 | 305 | 149 |
| Hainan | 71 | 49 | 42 | 53 | 48 | 30 | 22 |
| Hebei | 2133 | 2135 | 1733 | 2109 | 1961 | 1073 | 615 |
| Heilongjiang | 398 | 597 | 552 | 738 | 569 | 361 | 213 |
| Henan | 1611 | 1321 | 1137 | 1399 | 1205 | 672 | 420 |
| Hong Kong | 22 | 38 | 56 | 62 | 50 | 62 | 25 |
| Hubei | 1009 | 1066 | 974 | 1113 | 963 | 583 | 343 |
| Hunan | 763 | 636 | 600 | 734 | 595 | 389 | 251 |
| Inner Mongol | 415 | 544 | 424 | 535 | 500 | 239 | 116 |
| Jiangsu | 2294 | 1662 | 1578 | 2015 | 1499 | 831 | 420 |
| Jiangxi | 548 | 509 | 421 | 515 | 465 | 258 | 180 |
| Jilin | 1502 | 1570 | 1253 | 1491 | 1434 | 764 | 441 |
| Liaoning | 1159 | 952 | 885 | 1115 | 846 | 437 | 193 |
| Ningxia | 360 | 252 | 241 | 327 | 228 | 115 | 44 |
| Qinghai | 56 | 73 | 85 | 104 | 66 | 57 | 45 |
| Shaanxi | 1099 | 873 | 842 | 1081 | 798 | 462 | 216 |
| Shandong | 1241 | 1295 | 1174 | 1456 | 1170 | 695 | 435 |
| Shanghai | 3342 | 2565 | 2220 | 2932 | 2325 | 1112 | 454 |
| Shanxi | 1987 | 1618 | 1472 | 1795 | 1436 | 781 | 372 |
| Sichuan | 1652 | 1615 | 1455 | 1609 | 1423 | 820 | 427 |
| Tianjin | 448 | 428 | 441 | 522 | 391 | 265 | 133 |
| Tibet (Xizang | 4 | 77 | 40 | 71 | 72 | 20 | 18 |
| Xinjiang | 391 | 470 | 497 | 659 | 442 | 288 | 128 |
| Yunnan | 379 | 455 | 385 | 496 | 424 | 252 | 198 |
| Zhejiang | 1526 | 1298 | 1257 | 1605 | 1160 | 601 | 232 |
| **CHINA** | **30407** | **27709** | **24902** | **30551** | **25482** | **14485** | **7547** |

| NOx | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Province*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Anhui | 570 | 706 | 775 | 942 | 643 | 473 | 260 |
| Beijing | 392 | 599 | 703 | 695 | 799 | 728 | 247 |
| Chongqing | 211 | 273 | 300 | 332 | 239 | 183 | 131 |
| Fujian | 300 | 351 | 377 | 528 | 336 | 248 | 182 |
| Gansu | 249 | 295 | 305 | 395 | 281 | 209 | 132 |
| Guangdong | 961 | 1078 | 1234 | 1702 | 1050 | 819 | 539 |
| Guangxi | 291 | 383 | 420 | 549 | 381 | 312 | 202 |
| Guizhou | 221 | 293 | 299 | 363 | 268 | 190 | 122 |
| Hainan | 60 | 66 | 74 | 99 | 69 | 64 | 53 |
| Hebei | 1137 | 1431 | 1522 | 1916 | 1314 | 950 | 553 |
| Heilongjiang | 466 | 684 | 773 | 1050 | 643 | 470 | 261 |
| Henan | 880 | 962 | 1079 | 1398 | 902 | 675 | 376 |
| Hong Kong | 198 | 182 | 189 | 278 | 195 | 188 | 152 |
| Hubei | 520 | 701 | 760 | 920 | 661 | 507 | 302 |
| Hunan | 403 | 481 | 516 | 669 | 480 | 391 | 258 |
| Inner Mongol | 309 | 467 | 528 | 697 | 428 | 296 | 144 |
| Jiangsu | 1109 | 1323 | 1503 | 1969 | 1209 | 835 | 440 |
| Jiangxi | 296 | 395 | 391 | 496 | 380 | 272 | 186 |
| Jilin | 718 | 993 | 1044 | 1304 | 908 | 637 | 375 |
| Liaoning | 448 | 663 | 762 | 998 | 590 | 380 | 165 |
| Ningxia | 108 | 156 | 190 | 266 | 142 | 92 | 34 |
| Qinghai | 52 | 83 | 94 | 121 | 74 | 54 | 29 |
| Shaanxi | 310 | 413 | 498 | 666 | 392 | 311 | 179 |
| Shandong | 655 | 899 | 1042 | 1365 | 833 | 679 | 510 |
| Shanghai | 1399 | 1603 | 1845 | 2470 | 1498 | 1106 | 606 |
| Shanxi | 573 | 745 | 837 | 1072 | 662 | 433 | 186 |
| Sichuan | 461 | 607 | 630 | 778 | 594 | 486 | 361 |
| Tianjin | 466 | 478 | 575 | 742 | 454 | 445 | 405 |
| Tibet (Xizang | 11 | 79 | 79 | 129 | 76 | 37 | 19 |
| Xinjiang | 209 | 283 | 372 | 505 | 272 | 238 | 142 |
| Yunnan | 260 | 397 | 380 | 513 | 384 | 263 | 174 |
| Zhejiang | 782 | 933 | 1061 | 1425 | 873 | 639 | 387 |
| **CHINA** | **15023** | **19000** | **21158** | **27353** | **18031** | **13610** | **8113** |

| PM2.5 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Province*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Anhui | 558 | 528 | 496 | 470 | 528 | 415 | 290 |
| Beijing | 160 | 186 | 186 | 154 | 195 | 161 | 99 |
| Chongqing | 209 | 261 | 238 | 233 | 255 | 199 | 167 |
| Fujian | 173 | 165 | 165 | 191 | 165 | 133 | 120 |
| Gansu | 219 | 213 | 203 | 211 | 215 | 177 | 147 |
| Guangdong | 586 | 585 | 573 | 660 | 612 | 497 | 370 |
| Guangxi | 348 | 421 | 367 | 372 | 445 | 351 | 249 |
| Guizhou | 228 | 319 | 274 | 266 | 320 | 238 | 184 |
| Hainan | 89 | 70 | 62 | 61 | 76 | 60 | 42 |
| Hebei | 1012 | 1258 | 1164 | 1202 | 1238 | 980 | 811 |
| Heilongjiang | 421 | 414 | 379 | 380 | 415 | 306 | 211 |
| Henan | 670 | 677 | 667 | 731 | 669 | 549 | 463 |
| Hong Kong | 23 | 19 | 19 | 26 | 20 | 18 | 15 |
| Hubei | 555 | 633 | 589 | 595 | 654 | 540 | 398 |
| Hunan | 439 | 569 | 518 | 519 | 595 | 485 | 361 |
| Inner Mongol | 349 | 337 | 314 | 311 | 334 | 251 | 174 |
| Jiangsu | 922 | 775 | 799 | 906 | 744 | 596 | 485 |
| Jiangxi | 301 | 375 | 331 | 328 | 382 | 287 | 211 |
| Jilin | 599 | 698 | 677 | 677 | 690 | 565 | 434 |
| Liaoning | 328 | 371 | 370 | 412 | 355 | 272 | 215 |
| Ningxia | 75 | 73 | 79 | 97 | 69 | 52 | 40 |
| Qinghai | 53 | 56 | 64 | 70 | 53 | 47 | 39 |
| Shaanxi | 270 | 373 | 356 | 372 | 376 | 299 | 228 |
| Shandong | 219 | 372 | 356 | 418 | 355 | 271 | 240 |
| Shanghai | 1085 | 891 | 909 | 1016 | 875 | 709 | 557 |
| Shanxi | 562 | 790 | 837 | 952 | 774 | 725 | 693 |
| Sichuan | 752 | 854 | 727 | 704 | 889 | 684 | 497 |
| Tianjin | 130 | 131 | 142 | 146 | 127 | 114 | 93 |
| Tibet (Xizang | 14 | 50 | 48 | 64 | 49 | 31 | 22 |
| Xinjiang | 171 | 174 | 185 | 194 | 174 | 151 | 118 |
| Yunnan | 307 | 443 | 382 | 401 | 458 | 354 | 281 |
| Zhejiang | 506 | 579 | 553 | 602 | 559 | 397 | 276 |
| **CHINA** | **12332** | **13661** | **13028** | **13742** | **13662** | **10914** | **8531** |

**Table A 3** Air pollutant emissions in India by states, for the Baseline and the Mitigation scenarios (Mt/year)

| SO2 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| *State* | *2005* | *2020* | *2030* | *2050* | *2020* | *2030* | *2050* |
| Andhra Pr. | 482 | 870 | 1306 | 2621 | 805 | 835 | 460 |
| Assam | 37 | 94 | 124 | 173 | 94 | 110 | 94 |
| West Bengal | 467 | 834 | 1222 | 2470 | 791 | 839 | 440 |
| Bihar | 100 | 190 | 278 | 512 | 182 | 201 | 134 |
| Chhattisgarh | 281 | 522 | 839 | 1741 | 459 | 448 | 211 |
| Delhi | 52 | 84 | 127 | 256 | 81 | 94 | 55 |
| North East | 57 | 142 | 258 | 542 | 106 | 82 | 49 |
| Goa | 12 | 39 | 59 | 81 | 40 | 54 | 50 |
| Gujarat | 592 | 1178 | 1567 | 2669 | 1175 | 1348 | 963 |
| Haryana | 104 | 217 | 315 | 515 | 212 | 251 | 199 |
| Himachal Pr. | 33 | 87 | 122 | 193 | 82 | 89 | 79 |
| Jharkhand | 160 | 265 | 391 | 761 | 238 | 221 | 104 |
| Karnataka | 193 | 436 | 625 | 1071 | 426 | 490 | 362 |
| Kerala | 88 | 176 | 238 | 322 | 182 | 231 | 198 |
| Maharashtra | 798 | 1335 | 1916 | 3317 | 1401 | 1745 | 1211 |
| Madhya Pr. | 366 | 654 | 995 | 2008 | 603 | 624 | 322 |
| Orissa | 324 | 688 | 1063 | 2184 | 625 | 633 | 317 |
| Punjab | 141 | 271 | 412 | 745 | 258 | 302 | 213 |
| Rajasthan | 192 | 350 | 505 | 994 | 326 | 334 | 197 |
| Tamil Nadu | 672 | 913 | 1129 | 2019 | 906 | 942 | 640 |
| Uttaranchal | 11 | 24 | 34 | 48 | 24 | 30 | 26 |
| Uttar Pr. | 600 | 975 | 1448 | 2958 | 919 | 970 | 497 |
| West Him. | 5 | 6 | 8 | 13 | 6 | 6 | 4 |
| **INDIA** | **5765** | **10348** | **14979** | **28214** | **9938** | **10878** | **6825** |

| NOx | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| *State* | *2005* | *2020* | *2030* | *2050* | *2020* | *2030* | *2050* |
| Andhra Pr. | 361 | 473 | 608 | 1110 | 444 | 426 | 286 |
| Assam | 47 | 67 | 77 | 105 | 69 | 82 | 79 |
| West Bengal | 316 | 383 | 473 | 902 | 368 | 342 | 210 |
| Bihar | 98 | 130 | 154 | 246 | 129 | 126 | 94 |
| Chhattisgarh | 178 | 254 | 356 | 705 | 224 | 197 | 120 |
| Delhi | 99 | 114 | 138 | 215 | 114 | 132 | 117 |
| North East | 79 | 131 | 177 | 319 | 110 | 85 | 61 |
| Goa | 11 | 15 | 16 | 21 | 15 | 15 | 14 |
| Gujarat | 327 | 423 | 525 | 863 | 428 | 494 | 425 |
| Haryana | 124 | 185 | 231 | 355 | 181 | 204 | 169 |
| Himachal Pr. | 31 | 48 | 57 | 87 | 45 | 39 | 32 |
| Jharkhand | 94 | 126 | 165 | 304 | 115 | 99 | 63 |
| Karnataka | 168 | 233 | 273 | 440 | 227 | 217 | 160 |
| Kerala | 102 | 140 | 153 | 205 | 140 | 146 | 131 |
| Maharashtra | 464 | 566 | 704 | 1154 | 550 | 556 | 399 |
| Madhya Pr. | 277 | 372 | 480 | 864 | 347 | 325 | 198 |
| Orissa | 178 | 286 | 397 | 796 | 259 | 236 | 135 |
| Punjab | 139 | 190 | 240 | 392 | 184 | 192 | 129 |
| Rajasthan | 222 | 317 | 386 | 616 | 309 | 317 | 239 |
| Tamil Nadu | 382 | 426 | 473 | 761 | 426 | 433 | 345 |
| Uttaranchal | 23 | 31 | 32 | 35 | 32 | 32 | 23 |
| Uttar Pr. | 488 | 588 | 747 | 1335 | 575 | 595 | 403 |
| West Him. | 21 | 24 | 23 | 29 | 24 | 22 | 19 |
| **INDIA** | **4227** | **5521** | **6886** | **11859** | **5314** | **5312** | **3849** |

| PM2.5 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| *State* | *2005* | *2020* | *2030* | *2050* | *2020* | *2030* | *2050* |
| Andhra Pr. | 377 | 399 | 394 | 553 | 389 | 302 | 166 |
| Assam | 127 | 104 | 73 | 55 | 108 | 77 | 52 |
| West Bengal | 386 | 351 | 324 | 423 | 353 | 279 | 166 |
| Bihar | 195 | 164 | 139 | 147 | 169 | 136 | 112 |
| Chhattisgarh | 225 | 322 | 389 | 593 | 309 | 273 | 97 |
| Delhi | 24 | 27 | 30 | 45 | 31 | 37 | 38 |
| North East | 125 | 125 | 132 | 197 | 116 | 79 | 41 |
| Goa | 5 | 5 | 5 | 5 | 5 | 5 | 4 |
| Gujarat | 279 | 263 | 238 | 322 | 274 | 233 | 173 |
| Haryana | 89 | 77 | 70 | 86 | 78 | 63 | 49 |
| Himachal Pr. | 24 | 22 | 24 | 37 | 20 | 15 | 11 |
| Jharkhand | 207 | 302 | 350 | 483 | 297 | 274 | 96 |
| Karnataka | 270 | 231 | 180 | 198 | 235 | 163 | 113 |
| Kerala | 164 | 130 | 87 | 64 | 139 | 99 | 68 |
| Maharashtra | 418 | 443 | 429 | 573 | 438 | 349 | 216 |
| Madhya Pr. | 343 | 389 | 399 | 546 | 382 | 313 | 149 |
| Orissa | 314 | 391 | 416 | 600 | 381 | 307 | 110 |
| Punjab | 101 | 98 | 96 | 131 | 97 | 79 | 59 |
| Rajasthan | 410 | 354 | 291 | 313 | 357 | 268 | 195 |
| Tamil Nadu | 248 | 216 | 189 | 270 | 229 | 202 | 160 |
| Uttaranchal | 70 | 25 | 21 | 21 | 28 | 27 | 24 |
| Uttar Pr. | 971 | 901 | 838 | 939 | 911 | 799 | 666 |
| West Him. | 58 | 44 | 29 | 21 | 46 | 31 | 21 |
| **INDIA** | **5430** | **5382** | **5145** | **6622** | **5392** | **4409** | **2786** |

# APPENDIX V - Air pollution control costs

**Table A 4** Air pollution control costs in Europe, China and India by subregions, for the Baseline and the Mitigation scenarios. Costs are provided in million €2005/yr using a 4 percent interest rate.

| EU27 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Country*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Austria | 1078 | 1776 | 1703 | 1411 | 1682 | 1402 | 746 |
| Belgium | 1539 | 2344 | 2402 | 2316 | 2184 | 1906 | 1240 |
| Bulgaria | 432 | 1065 | 1421 | 1250 | 1011 | 1203 | 630 |
| Cyprus | 66 | 166 | 228 | 195 | 157 | 183 | 96 |
| Czech Rep. | 1454 | 1981 | 2186 | 1908 | 1847 | 1763 | 991 |
| Denmark | 855 | 1522 | 1513 | 1373 | 1473 | 1339 | 964 |
| Estonia | 150 | 384 | 362 | 305 | 318 | 237 | 94 |
| Finland | 500 | 819 | 906 | 892 | 725 | 684 | 475 |
| France | 5382 | 12148 | 13902 | 13296 | 11591 | 11587 | 7648 |
| Germany | 11505 | 15605 | 15176 | 13460 | 14522 | 12045 | 7242 |
| Greece | 882 | 2127 | 2353 | 1780 | 1983 | 2005 | 1015 |
| Hungary | 456 | 995 | 1101 | 912 | 914 | 871 | 399 |
| Ireland | 341 | 772 | 878 | 722 | 733 | 729 | 341 |
| Italy | 5424 | 8487 | 8986 | 7367 | 8147 | 7486 | 4215 |
| Latvia | 133 | 407 | 464 | 356 | 370 | 344 | 139 |
| Lithuania | 86 | 418 | 439 | 335 | 387 | 339 | 126 |
| Luxembourg | 119 | 424 | 448 | 393 | 406 | 374 | 215 |
| Malta | 50 | 69 | 74 | 62 | 68 | 61 | 32 |
| Netherlands | 2198 | 3575 | 4101 | 4420 | 3526 | 3852 | 3641 |
| Poland | 3478 | 7980 | 9043 | 7503 | 7495 | 7441 | 4189 |
| Portugal | 547 | 1383 | 1438 | 1055 | 1255 | 1119 | 584 |
| Romania | 743 | 2112 | 2605 | 2636 | 1931 | 2034 | 1181 |
| Slovakia | 253 | 592 | 736 | 643 | 521 | 529 | 283 |
| Slovenia | 224 | 565 | 520 | 449 | 517 | 407 | 230 |
| Spain | 3642 | 9164 | 10532 | 9167 | 8703 | 8748 | 5062 |
| Sweden | 962 | 1933 | 2218 | 2110 | 1825 | 1819 | 1211 |
| UK | 4304 | 6276 | 6502 | 5705 | 5883 | 5327 | 3265 |
| **Sum** | **46802** | **85091** | **92239** | **82021** | **80174** | **75834** | **46253** |

| CHINA | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Province*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Anhui | 477 | 2210 | 3305 | 4826 | 2106 | 2494 | 1753 |
| Beijing | 292 | 986 | 1258 | 1878 | 967 | 990 | 846 |
| Chongqing | 298 | 1064 | 1607 | 2317 | 988 | 1194 | 951 |
| Fujian | 268 | 1308 | 2041 | 3208 | 1276 | 1618 | 1313 |
| Gansu | 213 | 1141 | 1708 | 2627 | 1113 | 1364 | 1064 |
| Guangdong | 846 | 4028 | 6157 | 9738 | 3922 | 4688 | 3884 |
| Guangxi | 362 | 1454 | 2144 | 3161 | 1411 | 1679 | 1248 |
| Guizhou | 381 | 1045 | 1449 | 2114 | 987 | 1086 | 828 |
| Hainan | 42 | 281 | 424 | 663 | 282 | 360 | 293 |
| Hebei | 1111 | 4636 | 6589 | 9439 | 4470 | 5146 | 3710 |
| Heilongjiang | 286 | 2023 | 3337 | 5223 | 1962 | 2528 | 1915 |
| Henan | 684 | 3175 | 4924 | 7272 | 3055 | 3752 | 2552 |
| Hong Kong | 235 | 767 | 1016 | 1667 | 760 | 828 | 712 |
| Hubei | 547 | 2275 | 3191 | 4663 | 2188 | 2443 | 1878 |
| Hunan | 403 | 1860 | 2653 | 3964 | 1831 | 2164 | 1647 |
| Inner Mongol | 243 | 1254 | 2016 | 3048 | 1193 | 1430 | 1010 |
| Jiangsu | 993 | 3835 | 5434 | 8075 | 3642 | 3779 | 2741 |
| Jiangxi | 314 | 1337 | 1925 | 2886 | 1306 | 1544 | 1238 |
| Jilin | 686 | 2641 | 3749 | 5461 | 2506 | 2758 | 2107 |
| Liaoning | 407 | 1714 | 2466 | 3586 | 1588 | 1553 | 947 |
| Ningxia | 60 | 450 | 679 | 1024 | 423 | 419 | 238 |
| Qinghai | 50 | 255 | 390 | 582 | 240 | 283 | 202 |
| Shaanxi | 258 | 1387 | 2207 | 3373 | 1337 | 1610 | 1170 |
| Shandong | 513 | 2267 | 3122 | 4617 | 2160 | 2209 | 1812 |
| Shanghai | 872 | 4677 | 7097 | 10609 | 4484 | 5124 | 3332 |
| Shanxi | 593 | 2189 | 3085 | 4426 | 2051 | 2079 | 1392 |
| Sichuan | 539 | 2261 | 3194 | 4722 | 2202 | 2598 | 2107 |
| Tianjin | 200 | 1262 | 1894 | 2960 | 1226 | 1506 | 1277 |
| Tibet (Xizang | 8 | 161 | 232 | 363 | 153 | 131 | 70 |
| Xinjiang | 148 | 1078 | 1852 | 2902 | 1057 | 1447 | 1126 |
| Yunnan | 304 | 1381 | 1846 | 2752 | 1340 | 1449 | 1100 |
| Zhejiang | 900 | 3347 | 5300 | 8303 | 3219 | 3903 | 3001 |
| **Sum** | **13536** | **59746** | **88290** | 132450 | **57443** | **66158** | **49462** |

| INDIA | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***State*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Andhra Pr. | 140 | 609 | 811 | 1296 | 587 | 685 | 607 |
| Assam | 16 | 108 | 132 | 186 | 106 | 123 | 115 |
| West Bengal | 116 | 434 | 558 | 913 | 421 | 472 | 395 |
| Bihar | 33 | 147 | 178 | 268 | 144 | 158 | 135 |
| Chhattisgarh | 65 | 214 | 319 | 547 | 199 | 231 | 173 |
| Delhi | 48 | 349 | 451 | 705 | 341 | 416 | 425 |
| North East | 32 | 142 | 183 | 292 | 131 | 133 | 118 |
| Goa | 6 | 43 | 52 | 77 | 42 | 48 | 48 |
| Gujarat | 119 | 563 | 703 | 1095 | 551 | 631 | 581 |
| Haryana | 55 | 402 | 538 | 807 | 392 | 488 | 468 |
| Himachal Pr. | 13 | 78 | 102 | 154 | 75 | 88 | 85 |
| Jharkhand | 58 | 174 | 239 | 362 | 167 | 197 | 165 |
| Karnataka | 66 | 392 | 492 | 745 | 382 | 437 | 405 |
| Kerala | 52 | 418 | 537 | 786 | 409 | 497 | 488 |
| Maharashtra | 163 | 712 | 926 | 1467 | 689 | 803 | 737 |
| Madhya Pr. | 93 | 383 | 512 | 832 | 367 | 419 | 340 |
| Orissa | 68 | 269 | 387 | 660 | 255 | 295 | 223 |
| Punjab | 51 | 299 | 390 | 603 | 291 | 346 | 312 |
| Rajasthan | 85 | 470 | 597 | 899 | 458 | 531 | 480 |
| Tamil Nadu | 176 | 929 | 1179 | 1805 | 909 | 1079 | 1036 |
| Uttaranchal | 6 | 45 | 58 | 84 | 45 | 55 | 52 |
| Uttar Pr. | 154 | 637 | 842 | 1356 | 621 | 727 | 598 |
| West Him. | 9 | 66 | 80 | 114 | 65 | 74 | 71 |
| **Sum** | **1625** | **7884** | **10263** | **16054** | **7646** | **8931** | **8055** |

# APPENDIX VI - Impact indicators related to human health

**Table A 5** Loss in average life expectancy due to $PM_{2.5}$ (months) in Europe, China and India by subregions, for the Baseline and the Mitigation scenarios.

| EU27 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| *Country* | *2005* | *2020* | *2030* | *2050* | *2020* | *2030* | *2050* |
| Austria | 7 | 3 | 3 | 3 | 3 | 2 | 2 |
| Belgium | 12 | 7 | 6 | 6 | 6 | 5 | 5 |
| Bulgaria | 8 | 4 | 3 | 4 | 3 | 2 | 2 |
| Cyprus | 4 | 4 | 4 | 5 | 3 | 2 | 2 |
| Czech Rep. | 8 | 4 | 4 | 4 | 4 | 3 | 2 |
| Denmark | 7 | 4 | 3 | 4 | 3 | 3 | 3 |
| Estonia | 5 | 3 | 3 | 3 | 3 | 2 | 2 |
| Finland | 3 | 2 | 2 | 2 | 2 | 1 | 1 |
| France | 7 | 4 | 3 | 3 | 4 | 3 | 2 |
| Germany | 9 | 5 | 4 | 4 | 4 | 4 | 3 |
| Greece | 8 | 4 | 3 | 4 | 4 | 3 | 2 |
| Hungary | 10 | 5 | 4 | 5 | 5 | 3 | 3 |
| Ireland | 3 | 2 | 2 | 2 | 2 | 1 | 1 |
| Italy | 7 | 4 | 3 | 3 | 3 | 2 | 2 |
| Latvia | 6 | 4 | 3 | 3 | 4 | 3 | 2 |
| Lithuania | 6 | 4 | 3 | 4 | 3 | 3 | 2 |
| Luxembourg | 9 | 5 | 4 | 5 | 5 | 4 | 3 |
| Malta | 5 | 4 | 2 | 2 | 4 | 2 | 2 |
| Netherlands | 11 | 7 | 6 | 6 | 6 | 5 | 4 |
| Poland | 9 | 5 | 4 | 4 | 5 | 3 | 3 |
| Portugal | 7 | 4 | 3 | 3 | 4 | 3 | 2 |
| Romania | 9 | 5 | 4 | 4 | 4 | 3 | 2 |
| Slovakia | 8 | 4 | 4 | 4 | 4 | 3 | 2 |
| Slovenia | 7 | 4 | 3 | 3 | 4 | 3 | 2 |
| Spain | 5 | 2 | 2 | 2 | 2 | 1 | 1 |
| Sweden | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| UK | 6 | 3 | 3 | 3 | 3 | 3 | 2 |
| **Total** | **7** | **4** | **3** | **3** | **4** | **3** | **2** |

| CHINA | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| *Province* | *2005* | *2020* | *2030* | *2050* | *2020* | *2030* | *2050* |
| Anhui | 49 | 48 | 47 | 52 | 46 | 35 | 26 |
| Beijing | 69 | 72 | 68 | 59 | 72 | 56 | 36 |
| Chongqing | 48 | 52 | 50 | 54 | 50 | 38 | 30 |
| Fujian | 20 | 19 | 18 | 22 | 18 | 13 | 11 |
| Gansu | 15 | 15 | 14 | 16 | 14 | 11 | 8 |
| Guangdong | 32 | 31 | 29 | 35 | 30 | 23 | 18 |
| Guangxi | 32 | 32 | 31 | 36 | 31 | 24 | 18 |
| Guizhou | 30 | 32 | 30 | 33 | 31 | 23 | 18 |
| Hainan | 14 | 13 | 12 | 14 | 12 | 10 | 8 |
| Hebei | 50 | 53 | 50 | 53 | 51 | 40 | 31 |
| Heilongjiang | 12 | 13 | 12 | 13 | 13 | 9 | 7 |
| Henan | 51 | 50 | 49 | 55 | 48 | 38 | 30 |
| Hubei | 45 | 47 | 45 | 50 | 46 | 36 | 27 |
| Hunan | 42 | 44 | 43 | 49 | 43 | 33 | 24 |
| Inner Mongol | 9 | 9 | 9 | 10 | 9 | 7 | 5 |
| Jiangsu | 51 | 48 | 48 | 54 | 46 | 35 | 28 |
| Jiangxi | 36 | 38 | 36 | 41 | 36 | 27 | 20 |
| Jilin | 21 | 21 | 19 | 20 | 21 | 15 | 11 |
| Liaoning | 32 | 33 | 31 | 32 | 33 | 25 | 18 |
| Ningxia | 14 | 14 | 14 | 16 | 13 | 10 | 8 |
| Qinghai | 12 | 12 | 12 | 14 | 12 | 9 | 7 |
| Shaanxi | 31 | 33 | 32 | 35 | 32 | 25 | 19 |
| Shandong | 48 | 44 | 43 | 49 | 42 | 33 | 25 |
| Shanghai | 51 | 59 | 57 | 66 | 56 | 43 | 35 |
| Shanxi | 35 | 37 | 37 | 41 | 35 | 29 | 23 |
| Sichuan | 51 | 53 | 50 | 53 | 52 | 41 | 32 |
| Tianjin | 54 | 59 | 56 | 59 | 58 | 45 | 35 |
| Tibet (Xizang | 2 | 3 | 2 | 3 | 3 | 2 | 2 |
| Xinjiang | 8 | 8 | 9 | 10 | 8 | 6 | 5 |
| Yunnan | 16 | 17 | 16 | 17 | 17 | 13 | 11 |
| Zhejiang | 34 | 35 | 34 | 38 | 33 | 25 | 19 |
| **Total** | **38** | **38** | **37** | **41** | **37** | **29** | **22** |

| INDIA | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| *State* | *2005* | *2020* | *2030* | *2050* | *2020* | *2030* | *2050* |
| Andhra Pr. | 16 | 21 | 26 | 43 | 21 | 20 | 13 |
| Assam | 23 | 29 | 33 | 48 | 28 | 26 | 20 |
| West Bengal | 35 | 42 | 50 | 82 | 41 | 38 | 24 |
| Bihar | 28 | 31 | 37 | 56 | 31 | 30 | 22 |
| Chhattisgarh | 20 | 28 | 35 | 59 | 27 | 26 | 15 |
| Delhi | 50 | 55 | 63 | 95 | 57 | 58 | 48 |
| North East | 18 | 21 | 25 | 39 | 20 | 19 | 14 |
| Goa | 10 | 13 | 15 | 24 | 13 | 13 | 10 |
| Gujarat | 16 | 17 | 18 | 27 | 17 | 16 | 13 |
| Haryana | 32 | 34 | 40 | 60 | 34 | 33 | 26 |
| Himachal Pr. | 15 | 19 | 24 | 37 | 18 | 18 | 15 |
| Jharkhand | 31 | 42 | 52 | 83 | 41 | 39 | 21 |
| Karnataka | 12 | 15 | 18 | 28 | 15 | 15 | 11 |
| Kerala | 17 | 18 | 20 | 28 | 18 | 17 | 13 |
| Maharashtra | 39 | 47 | 55 | 84 | 47 | 47 | 35 |
| Madhya Pr. | 16 | 19 | 22 | 35 | 19 | 18 | 12 |
| Orissa | 24 | 34 | 42 | 71 | 32 | 30 | 17 |
| Punjab | 31 | 34 | 40 | 59 | 33 | 32 | 25 |
| Rajasthan | 17 | 18 | 19 | 28 | 18 | 16 | 12 |
| Tamil Nadu | 13 | 16 | 18 | 29 | 16 | 15 | 11 |
| Uttaranchal | 23 | 21 | 25 | 36 | 21 | 21 | 17 |
| Uttar Pr. | 36 | 39 | 44 | 67 | 39 | 37 | 28 |
| West Him. | 19 | 18 | 18 | 22 | 18 | 16 | 13 |
| **Total** | **23** | **27** | **31** | **48** | **26** | **25** | **18** |

**Table A 6** Premature deaths attributable to ozone (cases/yr) in Europe, China and India by subregions, for the Baseline and the Mitigation scenarios.

| EU27 | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Country*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Austria | 436 | 271 | 242 | 249 | 262 | 222 | 196 |
| Belgium | 465 | 339 | 327 | 337 | 334 | 315 | 302 |
| Bulgaria | 553 | 345 | 319 | 327 | 335 | 289 | 251 |
| Cyprus | 28 | 27 | 28 | 30 | 27 | 26 | 25 |
| Czech Rep. | 614 | 355 | 306 | 310 | 338 | 271 | 222 |
| Denmark | 204 | 148 | 141 | 146 | 145 | 134 | 127 |
| Estonia | 24 | 18 | 17 | 18 | 17 | 16 | 15 |
| Finland | 58 | 45 | 43 | 45 | 44 | 42 | 40 |
| France | 2672 | 1847 | 1717 | 1757 | 1802 | 1620 | 1501 |
| Germany | 4230 | 2933 | 2748 | 2811 | 2867 | 2598 | 2413 |
| Greece | 650 | 483 | 461 | 461 | 480 | 440 | 396 |
| Hungary | 807 | 503 | 450 | 459 | 482 | 399 | 331 |
| Ireland | 93 | 80 | 79 | 80 | 79 | 78 | 76 |
| Italy | 4663 | 3173 | 2952 | 2974 | 3107 | 2787 | 2557 |
| Latvia | 57 | 41 | 38 | 40 | 40 | 37 | 34 |
| Lithuania | 88 | 60 | 56 | 59 | 58 | 54 | 48 |
| Luxembourg | 37 | 22 | 20 | 21 | 22 | 19 | 17 |
| Malta | 27 | 19 | 18 | 18 | 18 | 17 | 15 |
| Netherlands | 459 | 336 | 327 | 337 | 331 | 315 | 302 |
| Poland | 1567 | 968 | 850 | 868 | 931 | 774 | 668 |
| Portugal | 583 | 446 | 427 | 428 | 437 | 409 | 388 |
| Romania | 1197 | 739 | 675 | 702 | 708 | 604 | 525 |
| Slovakia | 277 | 156 | 134 | 136 | 148 | 115 | 90 |
| Slovenia | 122 | 70 | 59 | 61 | 67 | 52 | 44 |
| Spain | 2081 | 1534 | 1440 | 1451 | 1501 | 1374 | 1292 |
| Sweden | 207 | 157 | 151 | 157 | 154 | 144 | 139 |
| UK | 2010 | 1706 | 1689 | 1715 | 1693 | 1659 | 1624 |
| **Total** | **24207** | **16820** | **15713** | **15996** | **16426** | **14807** | **13639** |

| CHINA | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***Province*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Anhui | 1997 | 2498 | 2637 | 3086 | 2473 | 2317 | 2051 |
| Beijing | 394 | 478 | 500 | 571 | 473 | 443 | 391 |
| Chongqing | 585 | 761 | 799 | 974 | 743 | 624 | 472 |
| Fujian | 1123 | 1399 | 1492 | 1817 | 1376 | 1230 | 1033 |
| Gansu | 686 | 838 | 895 | 1080 | 811 | 688 | 533 |
| Guangdong | 2003 | 2546 | 2696 | 3280 | 2518 | 2268 | 1931 |
| Guangxi | 1047 | 1347 | 1441 | 1818 | 1331 | 1146 | 891 |
| Guizhou | 813 | 1095 | 1162 | 1461 | 1069 | 877 | 631 |
| Hainan | 247 | 295 | 311 | 375 | 292 | 265 | 228 |
| Hebei | 2568 | 3080 | 3231 | 3704 | 3049 | 2844 | 2504 |
| Heilongjiang | 134 | 167 | 179 | 213 | 162 | 140 | 110 |
| Henan | 2886 | 3511 | 3703 | 4325 | 3466 | 3177 | 2725 |
| Hubei | 1777 | 2193 | 2319 | 2768 | 2148 | 1890 | 1533 |
| Hunan | 2067 | 2649 | 2777 | 3335 | 2604 | 2268 | 1825 |
| Inner Mongol | 556 | 659 | 702 | 818 | 642 | 567 | 465 |
| Jiangsu | 2509 | 3189 | 3367 | 3911 | 3164 | 3020 | 2729 |
| Jiangxi | 1306 | 1677 | 1781 | 2163 | 1644 | 1451 | 1194 |
| Jilin | 431 | 511 | 538 | 618 | 503 | 462 | 400 |
| Liaoning | 1463 | 1727 | 1812 | 2063 | 1711 | 1616 | 1451 |
| Ningxia | 124 | 150 | 161 | 192 | 145 | 125 | 99 |
| Qinghai | 149 | 173 | 183 | 217 | 168 | 144 | 116 |
| Shaanxi | 1155 | 1411 | 1508 | 1807 | 1369 | 1179 | 925 |
| Shandong | 3517 | 4195 | 4390 | 5007 | 4157 | 3931 | 3541 |
| Shanghai | 356 | 480 | 516 | 621 | 474 | 442 | 384 |
| Shanxi | 1241 | 1467 | 1552 | 1801 | 1441 | 1311 | 1119 |
| Sichuan | 2175 | 2737 | 2818 | 3351 | 2683 | 2267 | 1780 |
| Tianjin | 235 | 285 | 301 | 352 | 282 | 261 | 227 |
| Tibet (Xizang | 120 | 127 | 127 | 133 | 126 | 123 | 120 |
| Xinjiang | 324 | 362 | 399 | 459 | 357 | 341 | 298 |
| Yunnan | 779 | 932 | 949 | 1101 | 915 | 798 | 675 |
| Zhejiang | 1334 | 1672 | 1763 | 2066 | 1656 | 1549 | 1379 |
| **Total** | **36098** | **44615** | **47009** | **55486** | **43953** | **39764** | **33758** |

| INDIA | | Baseline | | | Mitigation | | |
|---|---|---|---|---|---|---|---|
| ***State*** | ***2005*** | ***2020*** | ***2030*** | ***2050*** | ***2020*** | ***2030*** | ***2050*** |
| Andhra Pr. | 2331 | 3034 | 3849 | 6662 | 2879 | 2815 | 1981 |
| Assam | 253 | 337 | 422 | 705 | 319 | 313 | 237 |
| West Bengal | 2021 | 2570 | 3256 | 5628 | 2448 | 2389 | 1658 |
| Bihar | 2031 | 2550 | 3170 | 5205 | 2474 | 2509 | 1849 |
| Chhattisgarh | 1054 | 1349 | 1712 | 2912 | 1275 | 1246 | 908 |
| Delhi | 394 | 436 | 522 | 655 | 432 | 478 | 422 |
| North East | 142 | 176 | 213 | 340 | 171 | 167 | 133 |
| Goa | 46 | 57 | 67 | 103 | 55 | 56 | 45 |
| Gujarat | 1956 | 2522 | 3142 | 5035 | 2486 | 2716 | 2248 |
| Haryana | 1057 | 1263 | 1567 | 2267 | 1237 | 1348 | 1120 |
| Himachal Pr. | 373 | 458 | 542 | 773 | 445 | 454 | 382 |
| Jharkhand | 1022 | 1291 | 1621 | 2757 | 1233 | 1212 | 870 |
| Karnataka | 1265 | 1599 | 1947 | 3175 | 1543 | 1532 | 1153 |
| Kerala | 583 | 713 | 820 | 1246 | 703 | 709 | 568 |
| Maharashtra | 3641 | 4484 | 5463 | 8529 | 4375 | 4531 | 3593 |
| Madhya Pr. | 2989 | 3696 | 4532 | 7109 | 3590 | 3706 | 2916 |
| Orissa | 1759 | 2404 | 3163 | 5799 | 2244 | 2144 | 1405 |
| Punjab | 1281 | 1572 | 2003 | 3006 | 1524 | 1663 | 1379 |
| Rajasthan | 1949 | 2476 | 3123 | 4868 | 2407 | 2591 | 2136 |
| Tamil Nadu | 1489 | 1821 | 2151 | 3418 | 1781 | 1789 | 1380 |
| Uttaranchal | 482 | 598 | 719 | 1062 | 587 | 615 | 487 |
| Uttar Pr. | 7474 | 9050 | 11262 | 17268 | 8870 | 9495 | 7414 |
| West Him. | 658 | 723 | 829 | 1070 | 710 | 736 | 659 |
| **Total** | **36250** | **45179** | **56095** | **89592** | **43788** | **45214** | **34943** |

# APPENDIX VII - Impact indicators related to ecosystems

**Table A 7** Acid deposition to forests in excess of the critical loads for acidification in Europe, for the Baseline and the Mitigation scenarios.

| | Total area | Forest area with acid deposition exceeding critical loads [km²] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Baseline | | | 'Mitigation' 2°C | | |
| | | 2005 | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| Austria | 35745 | 305 | 0 | 0 | 0 | 0 | 0 | 0 |
| Belgium | 6250 | 1676 | 1082 | 1117 | 1182 | 903 | 734 | 472 |
| Bulgaria | 48330 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cyprus | 1193 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Czech Rep. | 21646 | 5804 | 4945 | 3830 | 3931 | 4635 | 3291 | 2017 |
| Denmark | 2318 | 1763 | 315 | 282 | 353 | 273 | 221 | 169 |
| Estonia | 18383 | 26 | 0 | 0 | 0 | 0 | 0 | 0 |
| Finland | 240403 | 4773 | 1462 | 1458 | 1710 | 1436 | 1060 | 926 |
| France | 170655 | 15819 | 4637 | 4436 | 4445 | 4463 | 3678 | 3021 |
| Germany | 99799 | 51886 | 20223 | 14687 | 14875 | 17012 | 9716 | 5459 |
| Greece | 17614 | 1387 | 115 | 95 | 131 | 81 | 26 | 5 |
| Hungary | 13542 | 2412 | 791 | 641 | 803 | 618 | 209 | 0 |
| Ireland | 4254 | 1431 | 555 | 420 | 427 | 496 | 358 | 280 |
| Italy | 88907 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Latvia | 22446 | 5486 | 1140 | 1077 | 1213 | 1008 | 728 | 306 |
| Lithuania | 14373 | 6251 | 5637 | 5470 | 5593 | 5438 | 5011 | 4724 |
| Luxembourg | 672 | 129 | 128 | 126 | 126 | 126 | 121 | 121 |
| Malta | | | | | | | | |
| Netherlands | 5346 | 4780 | 4417 | 4392 | 4406 | 4365 | 4268 | 4139 |
| Poland | 87561 | 65551 | 31876 | 25902 | 24850 | 29309 | 19923 | 12254 |
| Portugal | 17752 | 2320 | 852 | 569 | 546 | 562 | 128 | 10 |
| Romania | 97964 | 48137 | 4292 | 3883 | 7753 | 1421 | 148 | 64 |
| Slovakia | 17008 | 1526 | 1241 | 855 | 1064 | 1128 | 73 | 0 |
| Slovenia | 10832 | 86 | 3 | 1 | 1 | 1 | 0 | 0 |
| Spain | 69515 | 4161 | 29 | 30 | 115 | 29 | 29 | 29 |
| Sweden | 150702 | 19162 | 2001 | 1716 | 2191 | 1687 | 1089 | 809 |
| UK | 19748 | 7970 | 2796 | 2269 | 2428 | 2483 | 1850 | 1502 |
| EU-27 | 1282960 | 252841 | 88536 | 73257 | 78142 | 77474 | 52659 | 36305 |
| Albania | 6517 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Belarus | 57864 | 9648 | 4737 | 5009 | 7043 | 2638 | 1780 | 562 |
| Bosnia-H. | 20005 | 3400 | 20 | 1 | 24 | 1 | 0 | 0 |
| Croatia | 17819 | 1238 | 528 | 528 | 533 | 528 | 115 | 36 |
| FYR Macedonia | 7206 | 1349 | 0 | 0 | 0 | 0 | 0 | 0 |
| R Moldova | 1676 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Norway | | | | | | | | |
| Russia | 1821560 | 20345 | 12295 | 12370 | 14491 | 10900 | 9153 | 4016 |
| Serbia | 26841 | 6452 | 2 | 1 | 70 | 1 | 0 | 0 |
| Switzerland | 9625 | 642 | 274 | 209 | 268 | 234 | 187 | 169 |
| Ukraine | 71135 | 3107 | 949 | 1078 | 1219 | 291 | 10 | 5 |
| Non-EU | 2040248 | 46183 | 18806 | 19196 | 23649 | 14594 | 11245 | 4788 |
| **Total** | 3323208 | 299024 | 107343 | 92454 | 101791 | 92068 | 63904 | 41093 |

**Table A 8** Nitrogen deposition in excess of the critical loads for eutrophication in Europe, for the Baseline and the Mitigation scenarios.

| | Total area | Ecosystems area with nitrogen deposition exceeding critical loads [km²] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Baseline | | | 'Mitigation' 2°C | | |
| | | 2005 | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| Austria | 40255 | 39975 | 27980 | 24413 | 24851 | 26727 | 20121 | 14851 |
| Belgium | 6250 | 6228 | 5563 | 5200 | 5326 | 5273 | 4955 | 4600 |
| Bulgaria | 48330 | 45155 | 27420 | 23797 | 23797 | 25014 | 18474 | 12949 |
| Cyprus | 2461 | 1671 | 1680 | 2081 | 2345 | 1671 | 1754 | 1680 |
| Czech Rep. | 27626 | 27626 | 27571 | 27564 | 27564 | 27564 | 27552 | 27523 |
| Denmark | 3584 | 3584 | 3584 | 3584 | 3584 | 3584 | 3583 | 3583 |
| Estonia | 24728 | 16741 | 7408 | 6692 | 7483 | 6905 | 5490 | 4303 |
| Finland | 240403 | 108859 | 58761 | 51829 | 59349 | 54813 | 40869 | 32458 |
| France | 180099 | 175626 | 155953 | 148107 | 150342 | 152825 | 141896 | 132936 |
| Germany | 102891 | 84309 | 66847 | 62323 | 62908 | 65454 | 58741 | 54281 |
| Greece | 52863 | 52672 | 51400 | 51683 | 51737 | 51285 | 50871 | 46623 |
| Hungary | 20805 | 20805 | 20684 | 19559 | 19588 | 20474 | 18845 | 17501 |
| Ireland | 2449 | 2123 | 1974 | 1970 | 1970 | 1959 | 1942 | 1895 |
| Italy | 124788 | 85347 | 57094 | 55006 | 55023 | 55697 | 49348 | 44076 |
| Latvia | 35823 | 35596 | 32587 | 31694 | 32611 | 31941 | 30470 | 28633 |
| Lithuania | 19018 | 19018 | 19014 | 18988 | 19014 | 18996 | 18955 | 18843 |
| Luxembourg | 1015 | 1015 | 1007 | 1006 | 1006 | 1006 | 1006 | 1006 |
| Malta | | | | | | | | |
| Netherlands | 4413 | 4046 | 3889 | 3889 | 3889 | 3869 | 3855 | 3806 |
| Poland | 90330 | 90186 | 88916 | 87845 | 88000 | 88508 | 86970 | 85033 |
| Portugal | 31029 | 29814 | 19304 | 18768 | 18852 | 18614 | 15962 | 13903 |
| Romania | 97964 | 18130 | 7586 | 7364 | 8546 | 6053 | 4417 | 1914 |
| Slovakia | 20532 | 20532 | 20489 | 20416 | 20444 | 20479 | 20235 | 19948 |
| Slovenia | 10996 | 10557 | 5974 | 4650 | 4684 | 5593 | 3232 | 1281 |
| Spain | 187087 | 176735 | 165165 | 161528 | 161668 | 163136 | 157234 | 150846 |
| Sweden | 150702 | 77927 | 54679 | 52972 | 56326 | 52623 | 48882 | 45411 |
| UK | 91962 | 21857 | 16154 | 15513 | 15476 | 15803 | 14481 | 12882 |
| EU-27 | 1618404 | 1176136 | 948684 | 908441 | 926383 | 925865 | 850137 | 782765 |
| Albania | 16954 | 16861 | 16632 | 16700 | 16710 | 16567 | 16492 | 15661 |
| Belarus | 64023 | 63407 | 61825 | 61825 | 62163 | 61562 | 61691 | 58983 |
| Bosnia-H. | 31892 | 28074 | 22574 | 22095 | 22481 | 21959 | 20163 | 18260 |
| Croatia | 31656 | 31652 | 31067 | 31066 | 31070 | 30977 | 30663 | 30200 |
| FYR Macedonia | 13945 | 13945 | 13864 | 13786 | 13773 | 13856 | 13214 | 11133 |
| R Moldova | 3483 | 3350 | 3197 | 3197 | 3197 | 3197 | 3197 | 3197 |
| Norway | 135283 | 23720 | 12984 | 12607 | 14015 | 11815 | 9932 | 7877 |
| Russia | 1821560 | 444283 | 133097 | 120150 | 163951 | 117152 | 87286 | 73669 |
| Serbia | 41108 | 39565 | 31636 | 29141 | 29464 | 30684 | 25888 | 21575 |
| Switzerland | 9625 | 9517 | 9198 | 9075 | 9146 | 9176 | 8793 | 8284 |
| Ukraine | 72200 | 72200 | 72200 | 72200 | 72200 | 72200 | 72200 | 71967 |
| Non-EU | 2241730 | 746575 | 408274 | 391841 | 438170 | 389144 | 349519 | 320806 |
| **Total** | 3860134 | 1922711 | 1356958 | 1300281 | 1364552 | 1315008 | 1199657 | 1103571 |